EROSION CONTROL

IN

MOUNTAINOUS AREAS

March, 1992

Japan International Cooperation Agency

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FOREWORD

This Manual on Erosion Control in Mountainous Areas has been compiled by JICA project "Afforestation in the Pantabangan Area" in the Republic of the Philippines as teaching material for the training activities of the project.

As the subject is relevant in many other developing countries, the Manual would also be of use for foresters in those countries when they attempt to tackle erosion problems. In the hope to help them in their jobs and also for a possible use by other JICA forestry projects as teaching material, the Manual is reproduced now as a JICA publication.

Care should be taken, however, that the content of the Manual which was prepared to fit local conditions of Central Luzon, the Philippines, needs to be modified when this is used in other areas or countries.

It is hoped that the Manual be further improved with comments and/or suggestions by the users.

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CHAPTER I EROSIONS IN MOUNTAINOUS AREAS

Section 1 Erosions In Mountainous Areas and Wild Torrens

Erosions in mountainous areas may be classified into the following in accordance with their types and generation sites.

- Hillside Slopes
  - Sheet Erosions
  - Hillside Landslide, Landslide or Landcreep
- Stream Beds
  - Mud Flow
  - Tractive Transportation

Soil which is generated by surface erosions, hillside landslides, landslides (landcreeps), etc. from hillsides are transported over torrentbeds until the majority become accumulated in the alluvial cone down the torrent. Additionally, soil accumulated on the torrentbed become eroded mud flow as well as the flow of water (tractive force), and the transported downstream. Drainage besin where this type of earth and woil movements occur may be segregated into the production zone, the transportation zone, and the sedimentation zone as illustrated in diagram 1-1. Torrents are therefore often devastated by the aforementioned erosions in the soil production zone. Such Streams are called wild torrents. The torrentbed sediment in torrents are vigorously agitated in the form of mud flow, and often cause disasters downstream by transporting immense volumes of sediment. The transportation zone is the span of torrent between the production zone and the sedimentation zone, where only sediment transport occurs. The sedimentation zone is in the form of alluvial cones by the deposited earth and sand from upstreams. These alluvial cone areas often become disaster sites since they are widely employed by mankind. In actual drainage basin, though, these aforementioned three zones are often not in order, and are connected with rivers downstream in orders such as the production zone to the sediment transport zone or in orders the production gone to the sedimentation zone.

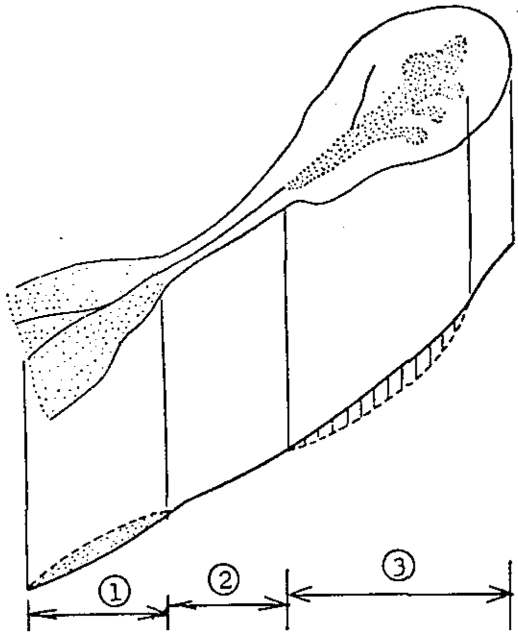


Diagram 1-1   Classification of Wild Torrent

Section 2   Primary and Provocative Causes of Erosion

The ratio and volume of erosion may be thought to be determined by the relative amount of the erosion generation effect (the volume of the provoking cause, force of erosion) and the erosion resistance of the ground or erodibility (the volume of the primary cause). The main factor of erosions is precipitation, and the erosion resistance is determined by the condition of the ground surface.

1. The Primary Causes and Their Dominant Factors

Primary Causes are elements such as geological structure, topography, soil, and forests which determined the erodibility of the land.
The topography mainly effects through slopes, and the steeper the slope, the more erodible the topography for both sheet erosion and landslides.
Soil characteristics are mainly dominated by the parent rock since soil is a weathered form of the parent rock. In general, viscous soil with

greater cohesion exhibit better erosion resistance than sandy soils. Forests greatly reduce erosions with its great functions to protect the soil surface and to secure surface soil with roots. Therefore, erosions are increased when landscapes become bare by timber drain. Smoke demaged lands and bare hills are some of the examples of the aforementioned phenomenon.

Erosions are caused by rock in the final stage crumbling into pebbles and being washed away. Therefore, the geological structure of the land greatly effects erosion. The following two factors describe the potentialty of erodible land. The first is the land being comprised of highly erodible mediums, and the second is when rockes have been transformed into clay and granules. The latter is caused by rock alteration. Terrain comprised with volcanic clastic materials is an example of naturally poor erosion resistance areas. Volcanic clastic materials are comprised of volcanic ash, volcanic gravel, and pumice, etc. and are extremely erodible. Large scale volcanic gullies where valley walls have fallen and wild torrents with large volumes of earth transported in the form of debris flow have been found in volcanoes and their vicinity. Furthermore, the Tertiary Green Tuff display poor cohesion characteristics being volcanic ejecta, and therefore are highly erodible. Hillside landslide and landslides often occur in Green Tuff regions.

The change of rocks in the lithosphere into granules and clay are called alteration. This alteration may be segregated into the cataclastic deformation and the hydrothermal alteration. On the other hand, the transformation of rocks into granule within the atmosphere is called weathering, and may be segregated into physical, chemical, and biological weathering processes. Cataclastic process among other forms of alterations, is always accompanied by weathering, and this combination greatly facilitates erosion of rocks.

(1) Alteration of Rocks

1) Cataclastic Process

This is the process where sub-surface rocks are destroyed by immense force under low temperature and pressure. Hereby, these rocks are transformed into so-called fractured rocks. For example, rocks such as shale are broken into small phyllite forms and become black coloured clay. On the other hand, hard sand-stones and granite are broken into block forms. Rocks which are broken physically by cataclastic process often weather chemically and become clay. The area which underwent cataclastic process generally have an expanse with a certain length and width. This expanse is called the fractured zone. This fractured zone appears in coincidence with the geological structure belt. Therefore, mountainous regions along the geological structure belt are highly erodible, and exhibit significance in large scale hillside landslide and landslide occurences. Rocks along this geological structure belt are broken and weathered throughout the region, causing hillside landslides and landslide as well as wild torrents.

2) Hydrothermal Process

Rocks in volcanic regions are transformed at times by hydrothermal alteration. These phenomena may be observed in hot springs. Rocks in hydrothermal alteration zone are chemically transformed by high temperature gas mainly comprised of hydrogen sulfide, sulfur, and steam into clay named hydrothermal deposit or sulfataric clay, exclusive of this region. This clay at times become the cause of landslides.

(2) Weathering of Rocks

1) Physical Weathering

Physical weathering may be segregated into temperature variation as well as freezing and thawing. Rocks are destroyed by the repetition of contraction and expansion when excessive temperature va variations occur since the individual minerals contained exhibit different thermal expansion rates. This phenomenon occurs in areas where the temperature varies greatly during the day and night. Additionally, rocks are also destroyed by the repetition of freezing and thawing of water seeped in cracks since congealed water generates cubic expansion. This phenomenon is the main cause for sub-surface rocks to become destroyed along joints.

2) Chemical Weathering

Chemical weathering may be segregated into oxidation, hydrolysis, and resolution. Cubic volume become increased during alteration by oxidation, and destruction become facilitated since large amounts of iron are contained in rocks. This form of weathering is called oxidation. Hydrolysis is a phenomenon where minerals become structurally transformed by water. This phenomenon plays an important role in the weathering of granites. Rainwater contains large amounts of carbon dioxide which resolve the mineral ingredients of rocks. This form of weathering is called resolution. This phenomenon is most significant in lime stone terrains, where harst topography exclusive of sucn areas are generated.

3) Biological Weathering

Plant roots penetrate cracks and mechanically destroy rocks. Additionally, carbon dioxide produced by plant putrefaction and respiration are dissolved with rain water which facilitate chemical weathering.

2. The Provacative Causes and Their Amount

Sheet erosions and sediment are proportional to the intensity and amount of rainfall. On the other hand, erosions in the form of landslides as well as muds flows do not necessarily occur frequently in heavy rainfall regions, but is greatly ruled by the intensity of rainfall beyond the extent of the region's normal rainfall intensity. From these points, the probable rainfall described by the return period exhibit great importance.

Snowfall, earthquake, and wind are some of the provoking causes other than rainfall. Snow deposits become avalanches which generate surface erosions and landslides. Besides the generation of avalanches, snow deposits carry away earth along with the flood of melted snow.

Those countries in Circumpacific Volcanic Zone are noted for earthquakes, and large magnitude earthquakes have been experienced. Earthquakes directly cause landslides as well as it is thought to be an indirect cause, by generating fissures in rocks. Drifting sand are caused by the wind in sandy regions and shifting of beach sand dunes occurs.

Section 3 Sheet Erosion

Bare-lands are eroded by rainfalls as though the individual top soil layers are peeled away independently from the surface layer. This form of erosion is called sheet erosion, and is exclusive in that the individual soil particles are washed away independently by water. Sheet erosions are frequently found on bare mountains as well as absorvable in granite and Tertiary period Layer hills. Other than the aforementioned, excessive sheet erosions may be seen in bare lands around volcanoes and landslide sites. Furthermore, sheet erosions are becoming more evident in artificial bare-lands produced by developments in recent years.

1. Development of Sheet Erosion

Two regions may be observed from the top and bottom of slopes in sheet erosion generation areas. The first is the region where erosion takes the form of uniformed removal of top soil. The other is observable in the lower regions where erosions are concentrated in the highly evident concave water-paths. The first type is called sheet erosion region and the other is called the rill erosion region (gully erosion region). The volume of erosions caused by rill erosions are considerably larger than those of sheet erosions, and gullies are developed within a short period of time.

Diagram 1-2 Bare mountain

Sheet erosions are greater with larger surface flow of rainfall on the ground. However, though, it is necessary to undersand that raindrops play an important role in generation of ground surface flows. Raindrops clamp, mix up, and splash upon contacting the ground, mixing-up and aplash are the important effects among the three. Narrow gaps between soil grains form paths for raindrops from the ground surface. These two effects clog the aforementioned paths with soil grains forming a thin soil layer which prohibits the infilteration of rain water. Hereby, surface flows become increased considerably.

Surface erosion volumes are relative to the water depth and the flow speed, and is considerably increased when the discharge becomes large. Therefore, uneven surface slopes emerge. Discharge becomes larger in cave regions where the rate of erosion becomes immensely increased. These phenomena genarate further concentration of rain water which accelerate erosions and gully generations.

2. Sheet Erosion Volume

Sheet erosions occur not only on bare-lands, but also on terrains with incomplete surface overlay. Therefore, top soil moves slightly by sheet erosions even in woods and grass lands. Additionally, erosion volume differs greatly depending on the topography, soil, and climate even in terrains with similar surface cover. Chart 1-1 describes the approximate annual volume of erosion on a slope with 15 degree incline. Woods and grass lands exhibit the lowest figures. However, woods lands incomplete overlay present poorer characteristics than well covered grass lands. Erosion volumes therefore are greater in prescribed burning lands and over-grazing forests than well conditioned grass lands.

Chart 1-1 Approximate Annual Erosion Volumes In Accordance With Surface Covering Types

Surface Covering	Devastated Land	Bare Land	Farm Land	Grass Land Wood Land
Annual Soil Erosion Volume (mm)	$10^2 \sim 10^1$	$10^1 \sim 10^0$	$10^0 \sim 10^{-1}$	$10^{-1} \sim 10^{-2}$

(by Takeo Kawaguchi)

Section 4 Hillside Landslide

1. Generation and Classification of Hillside Landslide

The phenomena where a part of the hillsids slopes lose stability resulting massive instantaneous downward movements of earth and sand is called hillside landslide. Scale of hillside landslides very greatly from small 10m^2 to large hillside landslides in excess of 10ha. Additionally, the thickness of earth fallen by hillside landslides vary from under one meter to over ten meters. Hillside landslides which frequently occur in mountainous regions by heavy rainfalls are of minimal scale individually, but become a cause for disasters when the occurring plots become excessive. On the other hand, large scale hillside landslides, occur at times in mountains at the final stage of rainstorms. Such hillside landslides may cause excessive disasters individually. The predominant provocative cause of hillside landslides may be said to be rainfalls, but it should not be forgotten that melting snow and earthquakes often also cause hillside landslides.

Hillside landslides in this literature are simply segregated into surface and deep layer hillside landslides although hillside landslides are actually classified into various types. Surface layer hillside landslides are when surface soil in the tree root penetration layer or slightly deeper depth collapses and falles, whereas deep layer hillside landslides are when rocks including underlying rocks in deep layers mountains collapse and fall. It is certain that hillside landslides possessing intermediate type of the two aforementioned types frequently occur, but it should also be noted that most of the two types of landfalls exhibit different characteristics. Surface hillside landslides are mainly caused by the surface condition (form) of hillside slope, and the earth causing the hillside landslides are mainly comprised with soil produced by surface weathering of rock bed. These types of hillside landslide are greatly effected by the intensity of rainfall. On the other hand, deep layer hillside landslides often are deeply related to the geological structure of mountainous bodies, where cataclastic process as well as weathering in the depths of rock beds often relate to the formation of brittle zones in rock beds which become sources of hillside landslides. Furthermore, generation of collapses are closely related to the total amount of rainfall.

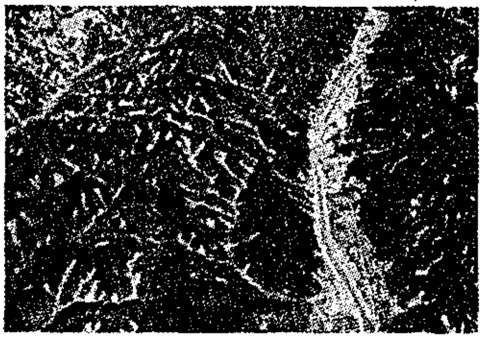


Diagram 1-3 Surface Layer Hillslide Landslide

Diagram 1-3 Deep Layer Hillside Landslide

2. Surface Layer Hillside Landslide

Diagram 1-4 describes example of a rainstorm which generated a hillside landslide. The graph indicates the danger of hillside landslide generation when there is an additional strong rainfall after water saturated surface soil. Mud flows are often generated in the lower foot to torrents when surface hillside landslide occur on hillside slopes. The following facts are known about the geneartion of surface hillside landslides on hillside slopes.

1) Occurs in the wide range between gentle slopes of 20 degrees and steep slopes of 45 degrees regardless of the geological structure.

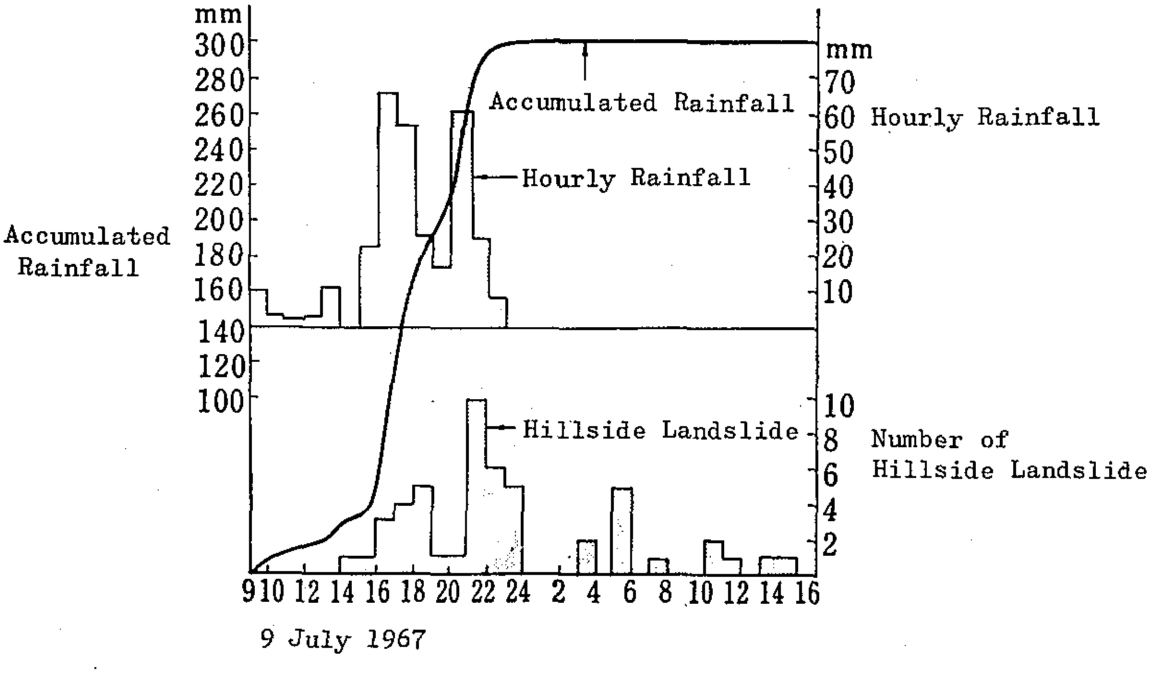


Diagram 1-4 Relation Between Rainfall and Hillside Landslides (Surface Landslides) in Kobe Japan (Hosono)

2) Majority of landslides occur within sunken regions of hillsides, and the points of generation are mostly near the inflection points of slopes.

3) Landslide generations tend to increase considerably in cutover areas.

Surface hillside landslides are when parts of the surface soil lose synamic stability by the flow of rain water generated temporarily within the surface soil, and become fallen out.
Almost all rainfall are absorbed into the ground in forests since permeability is great in such regions. Therefore, majority of rain water are transmitted into the depth of the earth during normal rainfall. However, when un-permeable layer exists below ground surface, the increased amount of rain water during rain stomrms generate a flow of rain water toward the slope with this layer as a border. This rain water flow destroys the dynamic stability of the soil horizon, and generates catastrophe. Catastrophes are easily caused particularly in places where the water discharge appears out to the ground surface in mid-hillsides.

3. Deep Layer Hillside Landslide

Parts of the mountainous body at times may fall from areas with reduced strength of rocks such as fractured zones where rocks become altered as well as in the depth of rock beds where rocks become weathered.
This type of hillside landslide is larger in scale than surface hillside landslides, and occur regardless of the topography. This type of hillside landslides exhibit similar features with landslides described in the following section, in that slippage generation exist within the rock bed as well as the relation of the ground water movement with the generation of catastrophe.
Deep Layer falls generated in fractured zones which can not be clearly segregated from landslide (landcreep) are at times called landslide type (landcreep) type hillside landslides. Furthermore, hillside landslides accompanying large amounts of ground water eruption at the point of catastrophe may be observed. In such case, one of the causes for catastrophe is thought to be the increased amount of ground water from rain storms which destroy and seal the ground water routes, and therefore producing excessive hydraulic pressure within the mountainous body.
The following precautionary phenomena similar to landslides (landcreeps)

may be observed at the generation of this type of hillside landslide:

1) Mud mixture and change in the discharge volume of ground water may be observed.

2) Minor falls may be observed in hillside foots and points of ground water discharge.

3) Cracks are generated in upper hill sides.

Section 5 Landslides (Landcreeps)

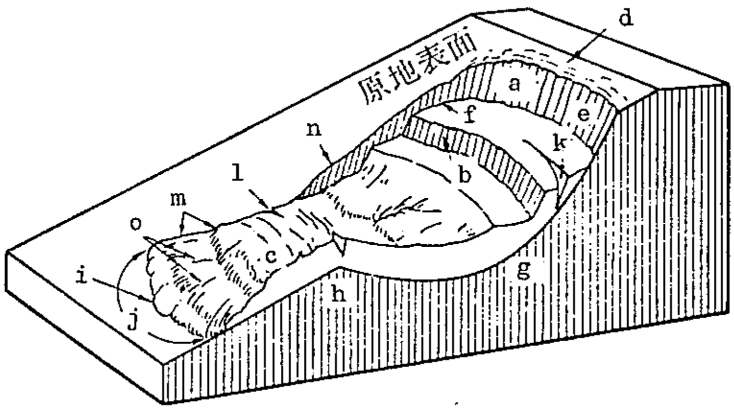
Landslides (landcreeps) are when fairly large areas of the ground creep slowly downward by ground water effects, etc. Landslides are observable throughout Japan. Landslide may be considered as a form of deep layer hillside landslide with a particular style of movement in the broad sense. Chart 1-2 lists the differences between landslide (landcreep) and hillside l landslide.

Chart 1-2 Landslide (Landcreep) and Hillside Landslide Comparison Table

	Landslide (Landcreep)	Hillside Landslide
Geological structure	Frequently generated in particular geological structure areas.	Minimal relation with geological structures.
Soil Nature	Slides mainly with viscous soil as the sliding surface.	Frequently occurs in sandy soil such as MASA, YONA, and SHIRASU also.
Topological Features	Occurs in gentle slopes with 5 to 20 degrees incline. Most frequently observed in areas with upland type terrain above.	Frequently generated in steep slopes with incline in excess of 20 degrees.
Activity Condition	Continuous Recurring	Sudden
Movement Speed	Generally slow. Mostly 0.01~10mm/day.	Fast. Over 10mm/day.

Clod	Minimal clod distortion. Usually moved while maintaining the original form.	Clod become deranged
Provocative Cause	Effected greatly by ground water.	Rain fall. Particularly effected by the intensity of rain fall.
Scale	Large 10^4-10^6m^2.	Small
Precursory Signs	Generation of cracks, subsidence, Protuberance, and ground water differentiations	Minimal precursory signs. Generally occur suddenly.

Many of the landslide generation areas are sites where previously occured landslides and deep layer hillside landslides have recurred. Therefore, entirely fresh landslide generations are relatively minimal.
Landslide regions usually exhibit exclusive topological features called landslide terrain. (Creeping land).



(a) Sliding
(b) Secondary cliff; scrap
(c) Toe
(d) Crown
(e) Summit
(f) Top part
(g) Sliding surface
(h) Spur
(i) Tip
(j) Toe Edge
(k) Tension Fracture
(l) Compression Fracture
(m) Upbearing Ground
(n) Side
(o) Original Ground Surface

Diagram 1-5 Individual Landslide Terrain Names (Sankaido, Yamada, Watamasa, Kobashi, "Realities and Countermeasures of Landslides and Slope Disintegration")

Sliding Cliff or scrap are found in the top-part of landslides, with sunken and level terrain immediately below, followed by gentle slopes. This sliding cliff and the sunken terrain below are exclusive of land slide terrains. Ground water eruptions are usually observed in the sunken terrain, and often comprise swamps, marshlands, and ponds. There Sliding cliff and ground water eruptions are clealy evident in the early stages of landslide, but become less noticeable over prolonged periods of time since Sliding Cliff become disintegrated, and as ground water eruptions become covered with debris which fill the sunken land. Secondary and third land slides occur once a landslide terrain is formed, and the number of Sliding cliff and level planes become increased, resulting in the formation of scalariform terrain. Crevice are caused by tension in the vicinity of Top-sliding cliff and by compression in the end regions during the initial movement stages of landslide. Furthermore, a particular type clay called landslide clay are found in the underground sliding surface.

1. Classification and Characteristics of Landslides

Majority of landslide cases are found in specific geological structure areas.

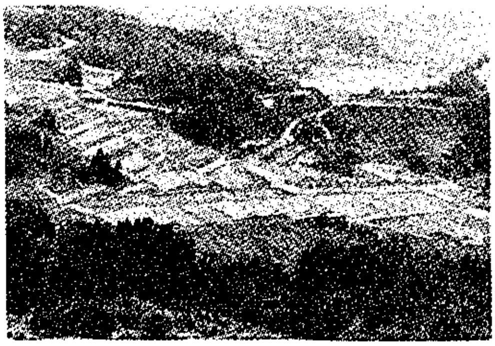


Diagram 1-6 Landslide Land

Majority of landslide are distributed among the Tertiary period layers, fractured zones, and hydrothermal alteration regions since these areas feature natural diathesis for landslide generation.

1) Tertiary period Layer Landslides

Since formation of Tertiary period Layer was relatively recent, and therefore, rocks of this layer are soft and exhibit poor coagulability.

Additionally, tertiary period layers exhibit excessive weathering and are easily transformed into clay since diastrophism was excessive during this period. Therefore, this layer may be considered to possess ample diathsis for landslide generations. 70% of landslides in Japan are concentrated in this tertiary period layer. On the countrary, landslide are not generated throughout the tertiary period layers, but tend to be concentrated in specific layers called the Miocene epoch in the tertiary period.

(2) Fractured Zone Landslide

This type of landslide are generated in fractured zones along the geological structure belt, and are also frequently generated along minor geological structure belts. Generally, mountains where this type of landslide are found exhibit steep inclines, and often cause catastrophic landslide during heavy rainfalls. Normal creepage is minimal, and is only few centimeters per year. Therefore the danger of landcreeps are often undetected in this type.

(3) Hot Spring Region Landslide

This type of landslide are caused by hydrothermal alterations, and are generated in volcanic and not spring areas. Landslide movements of this type tend to be vigorous, and exhibits great dengers of disasters once slippage occurs.

2. Generation of Landslides

Several provocative causes are inter-linked when landslide are generated. Provocative causes are mostly natural, such as rainfall, but artificial causes are increasing along with the progression of developments in recent years.

(1) Natural Provocative Causes

Rainfall increase the moisture content of the sliding plane and greatly reduce the resistance as well as soften the landslide clod and facilitate vigourous flows. Additionally, rainfall generates increased ground water pressure in landslide clod which further increase the pore water pressure, and adds to the generation possibilities of landslide. On the other hand, the amount and strength of rainfall

are not directly related to the creep speed and generation of landslide, and their relations between the cause and effects are complex. Fractured zone landslide are often caused by heavy rainfall, and landslide in high flow rate tertiary period layers are generally generated in conjunction with extended rainfalls.
Melting snow exhibit identical effects to the aforementioned extended rainfall. Furthermore, earthquakes often generate landslide.
Aside from the aforementioned, landslide are also generated by stream bank erosions where slope edges become washed away.

2) Artificial Provocative Causes

Stability of the clod become disrupted, and commence creepage when artificial factors effect slopes barely maintaining stability.
For example, landslides are generated by the cutting of slopes and excavation of tunnels during road work. Additionally, landslides are also generated by addition of fresh loads caused by embankments and erection of structures. Other causes which are relatively requently observed aside from the aforementioned are landslides generated by the change in ground water within surrounding hillsides due to submersion of dams as well as by the up and down quokes of the dam water level.

Section 6 · Mud Flow

Mud flow is a phenomenon where muds are washed down streambeds along with water. Large and small pebbles of various sized debris are intermixed with water and are washed downstream. Such form of sediment movement is called the massive transportation or mass movement. On the contrary to this phenomenon, in normal soil flow, the individual gravel on the streambed is transported by tractive force. This form of gravel movement is called the individual transportation. Massive boulder movements of boulders found on streambeds in water depths equivalent to, or shallower than the size of boulders cannot be explained with the general soil flow terms based on tractive force. Additionally, mud flows exhibit exclusive characteristics in their velocity of impact as well as movements in the bends of streams. With the aforementioned factors in consideration, mud flow are defined clearly apart from regular soil flow, and are distinguished in their unification with water. Furthermore, it should be noted that the intermixture ratio of debris against water varies among what are so-called mud flow.

1. Generation of Mud Flow

Generation of mud flow may be widely classified into the following:

1) Soil silted on steep incline streambeds are suddenly motivated with the current caused by heavy rainfall and become mud flow. Normally, water discharge are below the silted soil, but appear on the ground surface when the silt become water logged during heavy rainfall. Hereby, the silt become rapidly loosened, and mud flow are generated.

2) The fallen earth produced by washouts during heavy rainfall are combined with effusion water and are rushed downstream to become mud flow. Large scale catastrophes such as valley head erosions often become rapidly washed down and transform into mud flow. Often in such cases, the devastation by mud flow are not only caused by the impact of the fallen earth, but by the combination with the loosened silt washout.

3) Mud flows are also generated by the downstream silt washout caused by the impact of intercepting earth which are rushed downstream at the collapse of fallen earth temporarily clogging the stream.

4) Aside from the aforementioned, mud flows are known to be generated by the loosening of viscous landslides as well as by volcanic activities.[1]

1) Mud flows have been generated by massive volcanic ash and pumice effused by volcanic activiti s being washed out by rainfall or by snow melted by volcanic activities effecting the terrain likewise heavy rainfall. This type is often called mud flow. (Mt. Tokachi/1925)

2. Characteristics of Mud Flow

Mud flows exhibit the following characteristics:

1) Mud flow exhibit an exclusive form with large boulders at the head while being washed downstream as illustrated in diagram 1-7.

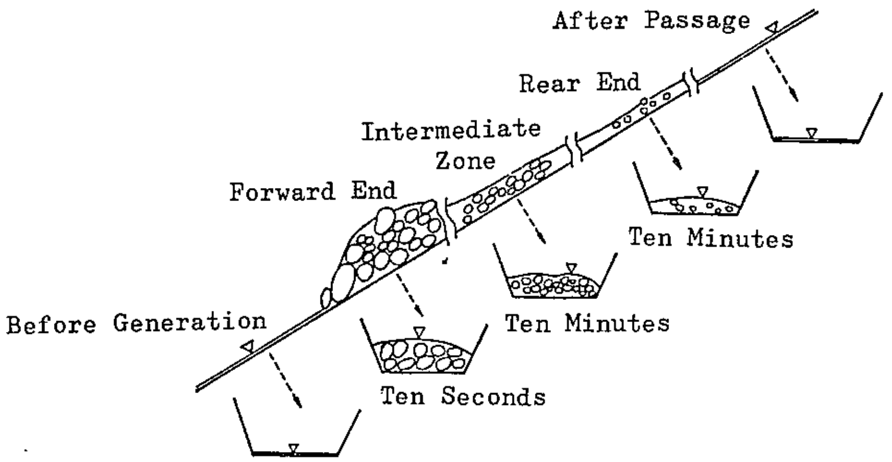


Diagram 1-7 Mud Flow Condition in Mt. Yake in Japan (Ministry of Construction Schematic)

2) The speed of mud flows are determined by its scale and the mixture ratio between debris against water as well as the incline of streambeds, etc. Additionally, they vary in accordance with the positions of generation, progression, declination, and dissipation of mud flows. Flow speeds vary from slower 1 - 2 meters per second to faster flow with speeds in excess of 20 meters per second. Flow speeds of large scale mud and stone flows cannot be reduced with several check dams, but minor mud flows are simply brought to a silt and a stop on a single check dam.

3) Mud flows are mostly generated on streambeds with incline in excess of 15 degrees. Mud flows come to a natural halt when the incline reduce to less than 10 degrees, and begin to form mud flow deposite. Large boulders are often found in the advancing end of these deposite (Diagram 1-8). Additionally, mud flows including large bebbles are hardly found in regions with less than 5 degree incline.

Diagram 1-8 Mud Flow Silt

4) Mud flows exhibit strong strait-line movement characteristics, and therefore destroy and overcome obstacles during advancement. This phenomena indicates that mud flow possess abundant inertia. Water level difference may reach 3 - 4 meters between the in and out sides of the flow in bends of streams. Therefore, large boulders are often left on the outer side hillsides.

5) U-formed valleys exclusive of streambeds after the passage of mud flows are formed.

CHAPTER II FOREST FUNCTION ON DISASTER PREVENTION

Section 1 Forest Function on Disaster Prevention and its characteristics

Trees may be considered to be living green structures with foundations in the ground. On the other hand, trees improve and secure their base of living which is the soil. This phenomenon becomes greatly strengthened in a gathering of trees which is the forest. Therefore, environment of surroundings terrains and atmosphere become greatly effected. The following describes the disaster preventative functions among the various phenomena observed in forests.

Forests function likewise to large surface structures, and therefore, large atmospheric movements are precluded, which in turn reduce the wind speed in the vicinity. This effect is called the windbreaking effect of the forest. Windbreaks, shifting sand control forests and so on are made using this effect. Furthermore, fog prevention forests are made as well as increased rainfall functions are generated with the atmospheric movement preclusion effect as well as the function to hold intra-atmospheric moisture of the forest. On the other hand, tree trunks of forests are used somewhat like protection fence for coastal salty wind protection, and flood prevention. Furthermore, the obstacle effect of forest crowns are employed for firebreaks and sound shields.

Forests produce a silting layer on the ground surface comprised of organic substances, which protect the ground surface and soften the top soil, making it fertile. Additionally, the top soil become stabilized and secured with the penetration of tree-roots in the sub-surface layers of the ground. Humus and defoliation on the ground surface prevent surface erosion generations by rainfalls and ground surface flows. Furthermore, surface soil stabilization by roots prevent land falls and falling rocks. Moreover, the soft and porous forest surface soil facilitate rain water infiltration which in turn decrease the flood discharge volume, and enhance water sources conservation. These phenomenon is called the water regulation effect of the forest.

Disaster prevention utilizing forests are considered to be highly useful as discribed in the following:

1) Large areas may be covered with forests. Erosion prevention in mountainous regions as well as water conservation and run off regulation may be accomplished with sand arresting structures or check dams, but abundant effects may be attained in large areas with forests although the individual forest effects may be small.

2) Forests may be produced at far less cost than architectural structures since they grow.

3) Forests planted for disaster prevention often are beneficial for environmental preservation as well as timber production.

4) The largest of the forest effects is the "OVERALL FOREST EFFECT". Forests provide multiple disaster prevention effects simultaneously as well as function as a source for timber production, environmental preservation, and vecveatiou, etc. Each individual effect may be accomplished more effectively by other measures, but the true importance of forests lie not in individual but in these overall effects.
The aforementioned are the disaster prevention effects of the forest. On the contrary, though, it must be noted that these effects must not be overestimated. This precaution is due to the forest foundation lying in the sub-surface depth of 1 - 2 meters below the ground.

Section 2 Forest Function on Windbreaks

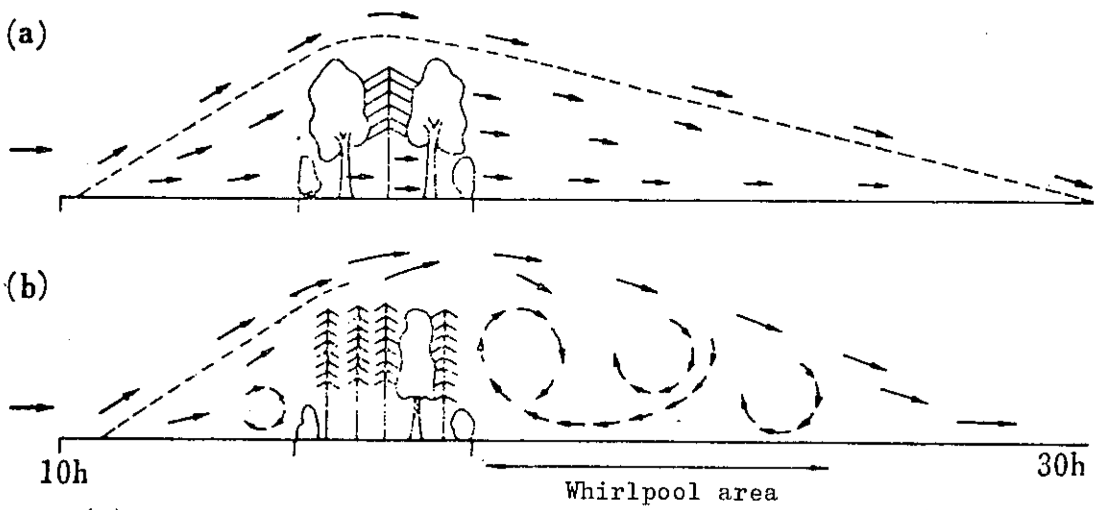
The utilization of forests as windbreaks may be segregated into inland (farmstead) and coastal windbreaks. Coastal windbreaks also function for shifting sand control, fog prevention, and salty wind prevention.

1. Inland Windbreaks

Tree belt width of inland windbreaks are generally narrow and the number of planting rows are less than seven. Additionally, the width is considered to be most efficient at 30 meters including renewal areas. Intra-forest ventilation effect become reduced when tree belt widths are excessive, resulting in decreased wind retardation areas.
The most ideal plantation of tree belts are in the right angle against the main wind, employing evergreen trees.
Major windbreak effects of forests appear in the lee side, but are

some what attained in the windward side also. The size of windbreaking zones are closely related to the density of forests.

When the forest density is large as illustrated in diagram 2-1 (b), ample wind retardation effects are attained. Hereby, air eddies are formed in the lee side, and the wind blown over the tree belt become rapidly lowered. With this reason, the windbreaking effect distance become shortened. On the other hand, in ideal density tree belts as illustrated in (a), portions of the wind are blown through with the rest blown over the tree belt. Air eddies therefore, are not generated in the lee side. Wind speeds may not be considerably decreased in such cae case, but the tree belt filters the wind, and therefore, windbreaking effects are attained over a large area.



(a) Ideal Density Tree Belt (h) Tree Height

(b) Overcrowded Tree Belt

Diagram 2-1 Wind Current in the Vicinity of Windbreak (by TOKUJI KASHIYAMA)

Ideal density is a condition where trees hold approximately 60% of the area when viewed from the front with averaged openings.

Diagram 2-2 illustrates the windspeed measurements taken at about one meter off the ground which is the determination factor for the employment of windbreaks.

The diagram illustrates the difference in the windspeed with and without tree belts in the form of ratio. Windspeeds are lowest in the ideal density tree belt, where the windspeed is reduced to about 30% at a distance equivalent to three to five times the height of the tree belt.

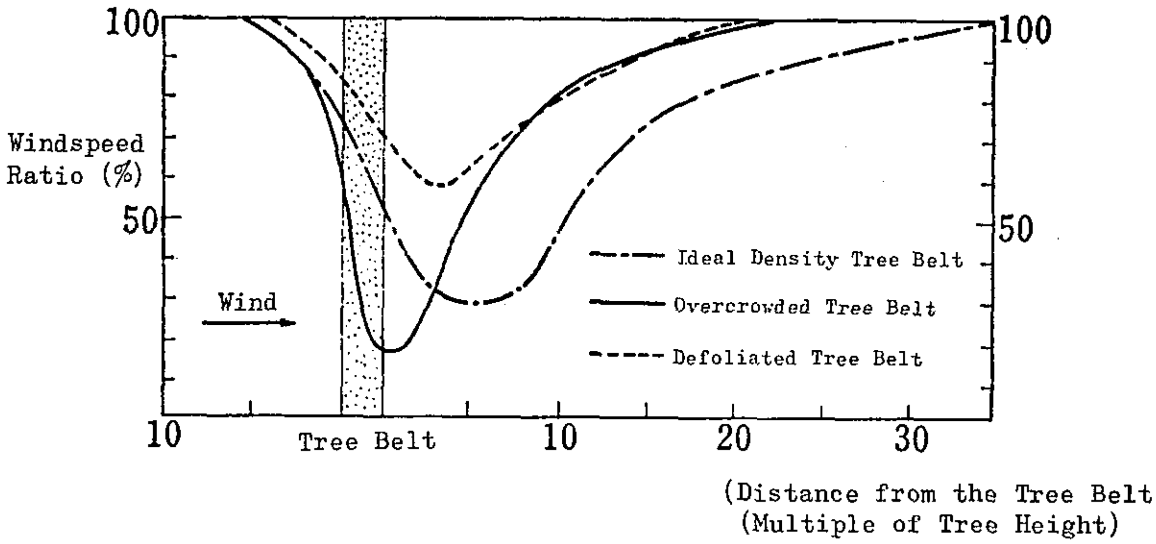


Diagram 2-2 Windspeed Reduction Effects of Narrow Tree Belts (Approximately 1 Meter Off The Ground) (By TOKUJI KASHIYAMA)

Additionally, it may be observed that windbreak effects are recognized with the reduction of wind-speed of 30% in distant zones of twenty times the height of the tree. Furthermore, windbreak effects are also recognized in zones of three to five times the geight of the tree in the windward side of the tree belt.

This windspeed transition effect of windbreaks prevent temperature near ground surface and ground surface temperatures from dropping as well as prevent atmospheric humidity reduction. Furthermore, effects such as reduction of water evaporation from the ground surface and weathering prevention are attained.

2. Coastal Windbreaks

Coastal windbreak tree belts tend to be wide since trees planted along the coast are hampered from growing by the crucial terrain conditions, and windbreak effects are therefore attained the growth of inland trees based on the sacrifice of the aforementiones water front plantation. The aeration rate and windspeed lowering distance are reduced in coastal windbreaks than inland windbreaks since the tree belt width become increased. On the other hand, inland direction sand shifting prevention effects are considerable with coastal windbreaks due to wide tree belts and the reduction of windspeed. Additionally, coastal windbreaks exhibit superb entrapment effects of salt contained in sea-breeze and sea fog. Heavy damages occur on agricultural products, power lines, and communication facilities, etc during typoons since salt wind with approximately 100 times the normal salinity density are known to have been blown inland. Diagram 2-3 illustrates an example of these effects of coastal windbreaks. The reduction of windspeeds, salt density, and sea fogs in the front and rear of the windbreak may be clearly observed in this graph.

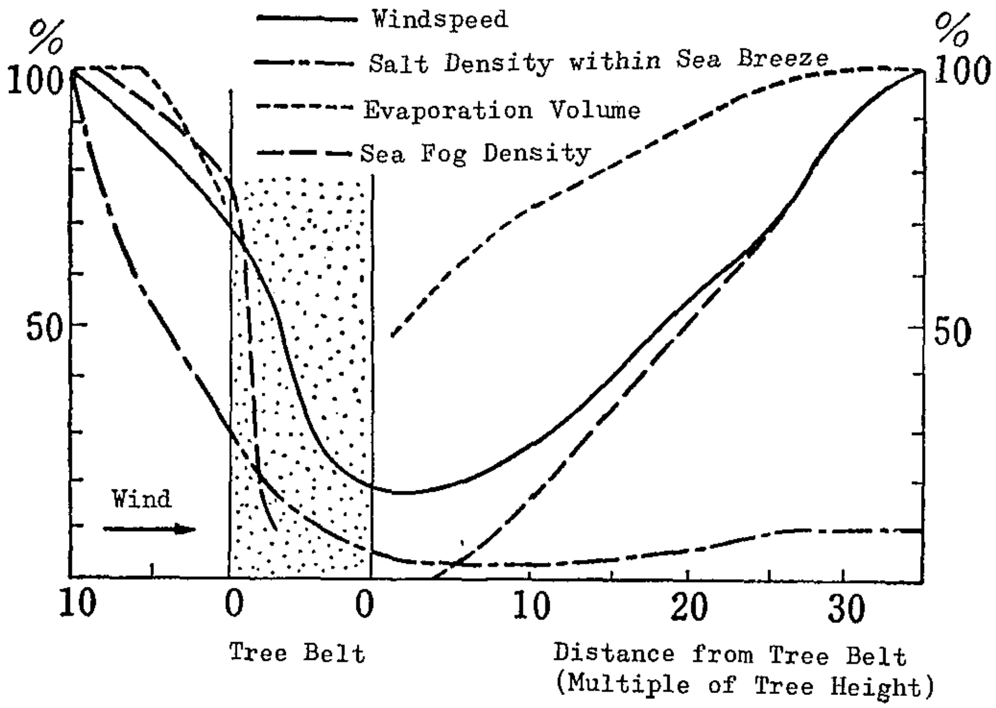


Diagram 2-3 Effect of Wide Coastal Windbreak Tree Belts (Approximately 1 meter off the ground) (TOKUJI KASHIYAMA)

Section 3 Forest Function on Erosion Prevention

Ground surface in forests are often covered with litter. Therefore, sheet erosion are rarely generated in wood lands. However, sheet erosion generations become increased when bare lands are produced by cutting of timber as well as by disturbance of wood lands since forest soils are soft and easily washed out.

Additionally, it must be noted that roots penetration exhibit ample surface soil stabilization effect, and therefore presnet abundant hillside landslide prevention capability. On the contrary, though, it must also be noted that the hillside landslide prevention capability of forest are said to be limited.

1. Forest Function on Surface Erosion Prevention

The ground surface is covered with thick humus layer, defoliation, fallen branckes when the crown is sealed in wood lands. Undergrass growth are observed when the humus layer, defoliation, and fallen branches are reduced in sparse density woods. In many cases, these surface covering matters function fully to absorb the impact from raindrops which is the cause of sheet erosions. It is by this function of covering matters that wood lands are free of surface runoff and exhibit high infiltration capacity. Even when partial surface runoff is generated, the flow becomes absorbed and dispersed by the surface overlay or soil grains are prevented from washing out by root penetration, and therefore are precluded from developing into large scale erosion such as gullies. However formation of partial bare lands become facilitated, accompanied by increased erosion when trees are cut down as illustrated in Chart 2-1.

Chart 2-1 Cutting Conditions and Annual Eroded Soil Volumes of Natural Japanese Red Pine Forest (Pinus densiflora)

Position of the Cutting Area and the Proportion with the Area	Annual Eroded Soil Volume (zon/ha)	Comparison of Annual Eroded Soil Volumes (Uncut : 1)
Overall Cutting and Stump Removal	28.53	78
Overall Cutting	3.66	10
3/4 Cutting Upper Area on Slopes	2.06	6
1/2 Cutting Upper Area on Slopes	1.14	3
1/4 Cutting Upper Area on Slopes	0.75	2
Uncut	0.35	1

Stand Age 30 years, 30 degree incline test ground (40 x 20m), in Okayama Prefecture.

(TAKESHI KAWAGUCHI)

Errosion volumes are greatly increased when ground surface are deranged upon felling.

Aside from the aforementioned, forests reduce the stand temperature change with the crown and surface overlay as well as prevent frost-lifting generated by the repetion of soil freezing and fusion.

Additionally, tree roots secure rocks and gravel in regions where rock beds and gravel appear on the ground surface, and also free crowns function greatly to prevent rocks and gravel from falling.

2. Forest Function on Hillside Landslide Prevention

Hillside landslides tend to be generated more often in unstocked areas such as grasslands and cut-over areas than stocked areas. It is thought that this is due to the surface soil being secured by the penetration in the sub-surface ground. This relation between the surface soil securing effect of root systems and generation of hillside landslides may be explained as described in the following:

Hillside Landslides Generation Prevention Effect (A): The root system spread throughout the sub-surface stabilize the surface soil and prevent generation of hillside landslides.

Hillslides Generation Effect (B): Large volumes of rain water are infitrated into the surface soil during heavy rainfall, facilitating the generation of surface layer hillside landslides.

Surface soil in forested hillside slopes are normally stabilized with the aforementioned root system effect (A). The effect (A) is storonger than effect (B) during normal rainfall (A > B), and therefore the terrain stability is maintained. However, hillside landslides become generated depending on the area during heavy rainfall when the effect (B) exceeds effect (A) (A < B).

It is when heavy rainfalls are encountered after trees have been cut down, and therefore enhancing the effect (B) that the conditions where the effect B exceeds effect A are liable to occure.

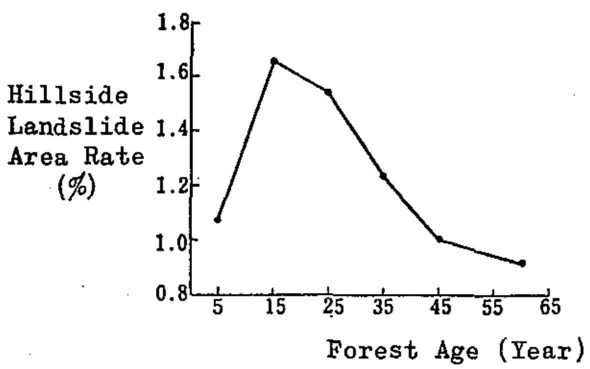


Diagram 2-4 Forest Age and Hillside Landslide Generations (NANBA)

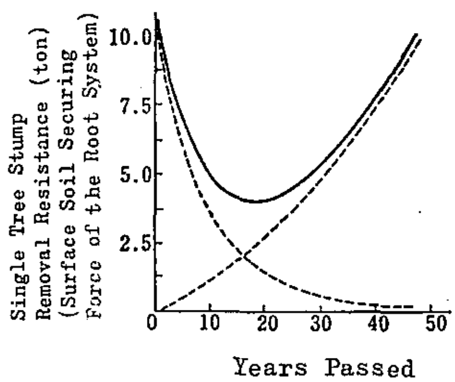


Diagram 2-5 The Change In Cedar Stump Removal Resistance Over The Years (KITAMURA, etc./Original Schematic)

This phenomenon is clearly observable that hillside landslides are frequently generated in thicket lands 10 to 15 years after falling as illustrated in diagram 2-4.

Diagram 2-5 illustrates the mechanism of this phenomenon. The surface soil securing effect of the root system become rapidly reduced over the years when the roots become rotten after fell. On the other hand, the surface soil securing effect of pole size trees become increased over the years. surface soil securing effect of root systems in general cut-over lands are described by the total of the two, and therefore is illustrated with the true line in the diagram. It is hereby observed that the effect (A) becomes most reduced around 10 years after feeling, facilitating the generation where the effect (B) exceeds effect (A) (A < B). It is therefore necessary to pay close attention when cutting trees down in landfall generation regions. It is important from these factors to plan the cutting to method prevent reduction of the surface soil securing effect of the root system by avoiding clear cutting and employing measures such as selective cutting as well as regeneration by sprouts.

Naturally, landfalls effected by tree cutting are surface layer landfalls, and therefore, generation of deep layer landfalls are considered to be far from this phemonenon.

Section 4 Forest Function on Runoff Control

Forests reduce the discharge volume of floods as well as prevent the discharge from decreasing during dearth of water periods. The former phenomenon is calles the flood control function and the latter is called the water resource conservation function of the forest.

1. Hydrological Cycle and Rainfall Runoff

Water on the earth are constantly circulated. Rainfall on mountains and level lands are stored on the ground surface or within the earth, with a portion later returning into the atmosphere through evaporation or transpiration. The remaining water flow into rivers. The form of these rain water storage, evaporation, transpiration, and river effluence vary greatly according to the condition of the ground surface.

For example, conditions of rain water storage or river run off greatly depend on the urbanity of the subject area such as forest land, bare land and city land etc. The water regulation effect of forests so to say, is to consider what function among the aforementioned hydrologic cycle forests share in contrast to other ground surfaces. Rainfall on hillside vegetation drop on the ground surface and become effluded into rivers after travelling through various routes. Graphs indicating the continuous measurement of river discharge is called a discharge curve (Hydrograph). The hydrograph (Diagram 2-6 is comprised of various rain water named ground surface, intermediate [1], and ground water effluence, travelling through the various sections of the hillsides. Effluence into rivers tend to be delayed with the depth of rain water infittration into the ground. The increased water during rainfall mainly consist of surface runoff and interflow, and river runoff during no rain periods are comprised with ground water effluence.

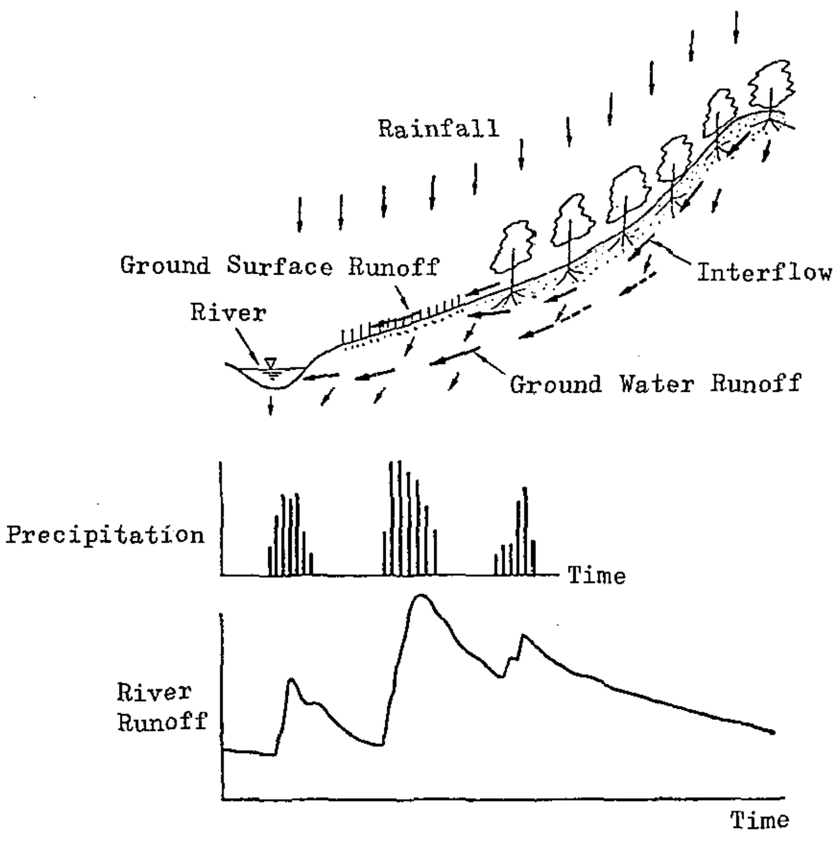


Diagram 2-6 Rain Water Runoff on the Hillside and Discharge Curve

When the intensity of rain fall is more than the percolation capacity of subsoil, rain water flows down the slope along the boundary layer of the surface and subsoil in case that the surface soil are more porous than subsoil as in forests.

This phenomenon is called the interflow.

2. Forest Function on Flood Control and Head Waters Conservation Flood

Flood discharge is increased along with the increase of the volume of surface runoff during rainfalls. On the contrary, flood discharge are decreased with the increase of rain water infiltration into the ground to become ground water, and instead, the river discharge increase during dearth of water periods.

The effects of the forest on rainwater discharge are explained in the following.

1) Forest soil are porous, and infiltrate most of the rainfall under the ground. Therefore, ground surface flows are hardly generated. Infiltration capacity is the measurement of the ground surface ability to infiltrate rainwater. Chart 2-2 describes the change in the infiltration capacity according to condition of the ground surface in the form of final infiltration capacities. The *infiltration capacity where the infiltration capacity* become constant when the ground become water logged by rainfall, is called the final infiltration capacity. It is obvious from this chart that forests exhibit superb infiltration capacities.

Chart 2-2 Variations and Infiltration Capacities of Vegetations

Type of Vegetation	Last Infiltration Capacities (mm/hr)
Coniferous Forest	246
Broad Leaved Forest	272
Cut-over Area	160
Grass Culture Area	191
Newly Hillside Landslide	99
Forest Road	11

2) Surface soil in forests tend to maintain porosity into greater depth than other vegetative land, and therefore exhibit better rain water storage as well as infiltration to the depth of the earth compared to other ground surface conditions.

3) Large amounts of rain water are stored in the surface soil in forests to supplement water shortage caused by transpiration. Therefore the amount of rain water becoming river discharge tend to be slighly less than other ground surface conditions.
The change in the flood discharge based on the aforementioned features of forests, when lands become bare or when trees are cut down are explained in the following:

   i) The infiltration capacity of the grounds surface become considerabley reduced when the aforementioned features 1) and 2) of the forest are eliminated due to increased bare lands caused by loss of forests by fire or by excessive ground surface devastation. In such case, most of the rain water become surface runoff, and the flood discharge increase considerably. An example of this phenomenon is illustrated in diagram 2-7. The diagram explains the forest restoration by planting on bare lands with the accompanying flood discharge reduction.

   ii) The aforementioned features 1) and 2) are maintained, and the feature 3) become changed when proper soil preservation are performed after cutting. The rain water volume to supplement the water shortage of the soil become reduced by decreased transpiration caused by forest cutting. Therefore, flood discharge are somewhat slightly increased in contrast with forests. The following explains the relations between the forest and river discharge during water famine periods:
   Increase in the ground water storage volume results increased river discharge during famine periods since river discharge during this period are comprised mainly with effluence from ground water storage in mountainous regions. Forests exhibit better infiltration capacity than any other types of vegetation or ground surface, and therefore, the greatest volume of rain water are infiltrated underground. Viewing from this point, it could be said that forests play an important role in increasing the river discharge during famine periods.

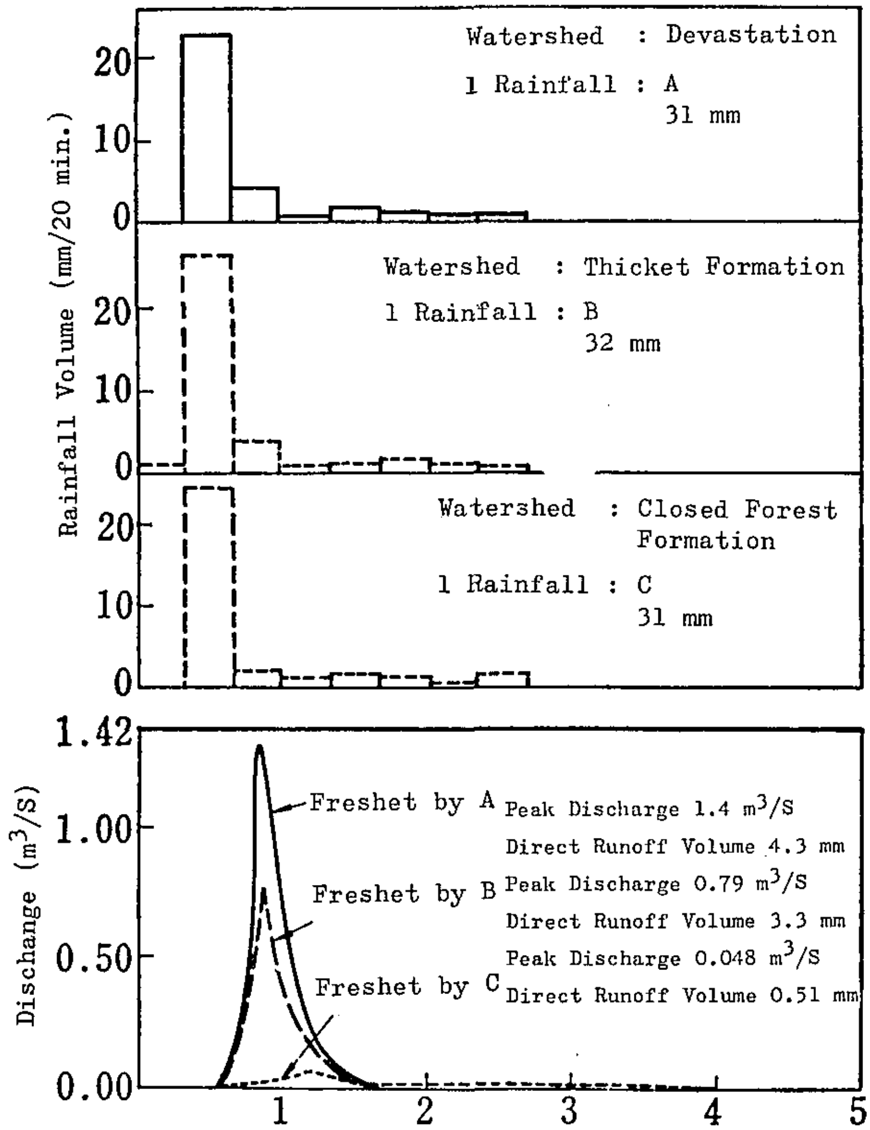


Diagram 2-7 Example of Direct Runoff Reduction and Runoff Time Extension due to Silviculture in Devastated Areas
(Hideaki NAKANO/"Forest Hydrology" 1976 Japan)

Forests dissipate moisture stored in the soil into the atmosphere through transpiration. This dissipation through transpiration reduces the volume of rainwater infiltration to the ground water storage. Therefore, it is desirable to reduce the volume of dissipation through transpiration in order to increase the discharge during dearth of water periods. However, forest cutting aimed at the reduction of transpiration expose the forest to the danger of ground surface devastation, resulting in generation of surface run off and increased erosion volumes. For example in Japan, transpiration volumes in most parts are relatively less than rainfall, and therefore it is more important from the viewpoint of water resource conservation to enhance rain water infiltration underground than reducing the transpiration volume. Transpiration volumes generally tend to become reduced and rainfall increased with the elevation in altitude at identical points. With these factors in consideration, it may be concluded that it is important to develop well conditioned forests in high elevation far up areas of water source which can infiltrate abundant volumes of rain water underground, while reducing dissipation through transpiration in order to increase the ground water storage.

CHAPTER III DESIGNING AND CONSTRUCTION OF HILLSIDE WORK

Section 1 Objectives of the Hillside Works

Hillside collapsed by heavy rain or earthquakes lacks vegetation overlay, and the surface is swept away. Therefore, the surface layer soil is washed down the slope with each succeeded rainfall, and devastation become further progressed. Additionally, the swept down soil and gravel accumulate on streambeds, and become potential cause of large scale disasters such as floods.

Diagram 3-1

Soil inadequate for the growth of vegetation appears on such devastated hillsides, precluding the early stage entry of plants. Devastated subject requiring restoration, such as where the vegetation overlay had been artificially removed by forest development, subject frequently found and subject potential danger for disasters. We hereby must study effective hillside work methods in order to prevent disasters through restoration of denuded lands for enhancement of the disaster prevention effects of forests, which in turn stabilize the terrain and assure water resources.
Hillside devastation are generally accompanied by wild torrents.
Therefore hillside works explained in this chapter are usually designed and

executed in combination with torrent works explained in the following chapter.

Section 2 Planning the Hillside Works

Designing stages of hillside works may be segregated two procedures. The first is by planting vegetation upon careful accomplishment of foundation work, and the other is to plant vegetation with minimal alteration to the topography. The former method exhibits high rates of success, but is time consuming and costly. The latter method is economical, but risks the generation of partial erosions. Therefore, it is important to apply the most adequate type of work method and procedure in accordance with the conditions of the subject topography upon surveying the work execution area, since either method exhibit the aforementioned benefits as well as shortcomings.

Section 3 Surveying for Designing the Hillside Works

Topographic survey results of areas in the vicinity of scheduled work execution site are used as the basic data for designing hillside works. Topographic surveys are accomplished by traverse, using equipments such as transit and pocket compass, etc., in order to obtain information on the topographic conditions of the devastated land and vicinity for the production of a plane schematic. Major surveying points during this survey must be on immovalbe points, since they will be used as control points for future surveys and execution of works. The scale should be between 1/500 to 1/1000 with a contour interval of 5 to 10 meters.
Profile leveling or Longitudinal leveling determines the type, layout, and extent of the work, and is performed to estimate the soil volume of grading works explained in the following Section 4, during hillside foundation works. This form of survey is accomplished with a level or a pocket compass. Directions of surveys and survey lines are to be determined upon studying the change in landscape changing points, proposed structure erection sites, and land classification *(1).

*(1) Land classification is a term for classifying lands into stream bed area and hillside landslide area, with further classification of hillside landslide area into denuded hillside area and sedimentation area.

Cross sectional leveling is performed in order ro estimate the basic figures for various foundation works, and selection points of this survey are in accordance with these of the Profile leveling

Close attention must be paid to the directions of survey lines in order to attain accurate figures. Levels or pocket compasses are employed for this survey depending on the accuracy desired.

Section 4 Types of Hillside Works

Restoration of devastated hillsides by replanting is accomplished by applying hillside foundation work first in order to clear and stabilize the uneven hillside surface. This is then followed by the application of hillside seeding and planting work in order to permanently stabilize the hillside surface with vegetation overlay.

The types of hillsides works are mainly segregated by the utilized materials, and the commonly methods are as listed in the following.

- Hillside Work
  - Foundation Work
    - Grading Work
    - Retaining Work : Wet Masonry, Dry Masonry, Concrete, Square Crib, Concrete Plate, Wire Cylinder (Gabion), Fascine Masonry, Fence Work, etc.
    - Buried Work : In accordance with the work types of the Retaining work
    - Drainage Work
      - Water channel Work : Wet Masonry, Dry Masonry, Concrete, Concrete Piping, Sodding, Stone Plastering, Wire Cylinder (Gabion), Corrugated Piping, etc.
      - Closed Conduit Work : Wire-Cylinder(Gabion), Gravel Fascine, Concrete Piping, Vinyl Chloride Piping, etc.
  - Planting Work
    - Sodding Work: Triple sheet sodding, Quintuple Sheet sodding, Sodding Step, etc.
    - Simple Terracing Work : Stone, Miscanthus, Concrete Plate, Sod, Fascine bundle, Straw, Log Other planting Material, etc.
    - Covering Work : Straw, Straw Mat, Fascine, Other Planting Material, etc.
    - Slope Seeding Work : Manual Seeding, Seed Shooting, Strip Seeding, Overall Seeding, Helicopter Seeding etc.
    - Planting Work

Although various types of work methods and procedures are available as listed in the table, determination among foundation or planting works should be only made upon studying the actual topography as well as the survey data, for the employment of the most appropriate method in compliance with the topography, soil, and climate of the proposed work site area with the ease of material procurement and transportation in consideration. Furthermore, designs must be processed separately even within the same job for well vegetated areas such as the sedimentation zone and poor soil condition regions where woil dressing is required.

Section 5 Hillside Foundation Work

1. Grading Work

Hilldides devastated by landslides exposes uneven surface as well as steep inclines, and are highly unstable. This surface unevenness become further dissected with each rainfall due to the sheet flow concentrating in the sunken sections of the hillside.
Inclines must be reduced as necessary and the surface must be smoothed on such hillsides since the applied measures are easily destroyed. Works performed for the improvement of such conditions are called grading works.
The most ideal state of the grading work is when the overall uneven surfaced slopes are graded with the angle of repose of the particular soil quality as illustrated in chart 3-1.
However, it is highly important to plan and execute this work in conformance with form of the topography, since removal of large soil volumes are not only costly, but risks the danger of silt deposited in the sunken sections to shift and coause unexpected disasters by rainfalls.

Diagram 3-2 Execution of Grading Work

Chart 3-1   Soil Variations and Angles of Repose

Condition / Type of soil	Dry	Low Moisture Content	High Moisture Content
Clay	$20^{\circ} \sim 37^{\circ}$	$40^{\circ} \sim 45^{\circ}$	$14^{\circ} \sim 20^{\circ}$
Sand	27 ~ 40	30 45	20 ~ 30
Ballast	30 ~ 45	27 ~ 40	25 ~ 30
Regular Soil	20 ~ 40	30 ~ 45	14 ~ 27

The works are started from the top of the slope downward to the valley. Soil are removed from protruded sections, and are used to fill the sunken areas. Retaining structures must be erected prior to the execution of this work since secondary disasters may be generated by rain or snow falls when these filling silts are excessive although these soil have been sufficiently compacted.

Grading works are normally performed with tools such as picks, shovels, and mattocks.

2. Hillside Retaining Work

This work is performed to erect structures on necessary points of hillsides in order to reduce the slope incline, support collapsible slopes, prevent washout of grading soil, and to preserve drainage work.

Therefore, these structures must be erected on sturdy foundations where they are safe against the earth pressure from the top as well as free of slippage generation in the bottom, since such structures are required to maintain the hillside soil rigidly and stably under any condition.

Furthermore, measures such as step formation are necessary to leave spaces between the first structure and the second structure in order to decrease the generated pressure.

Moreover, it is necessary to prevent from damaging the tops of retaining structures by grading soil fillings and rock falls since retaining structures are often erected prior to grading work.

1) Wet and Dry Masonry

This method is employed commonly when natural rocks and stones which are materials for masonry are readily available on the job site. Artificially produced materials such as concrete blocks to have super seded natural stones. Concrete block retaining work vary in types such as employment of conventional stone material formed blocks with conventional execution procedure, assembly and erection employing square rigging likewise architectural technology using plaster and steel reinforcement, and others with intermediate process of the aforementioned two. However, it must be further noted that the determination of the type of work process must be made in compliance with the condition of the work site.

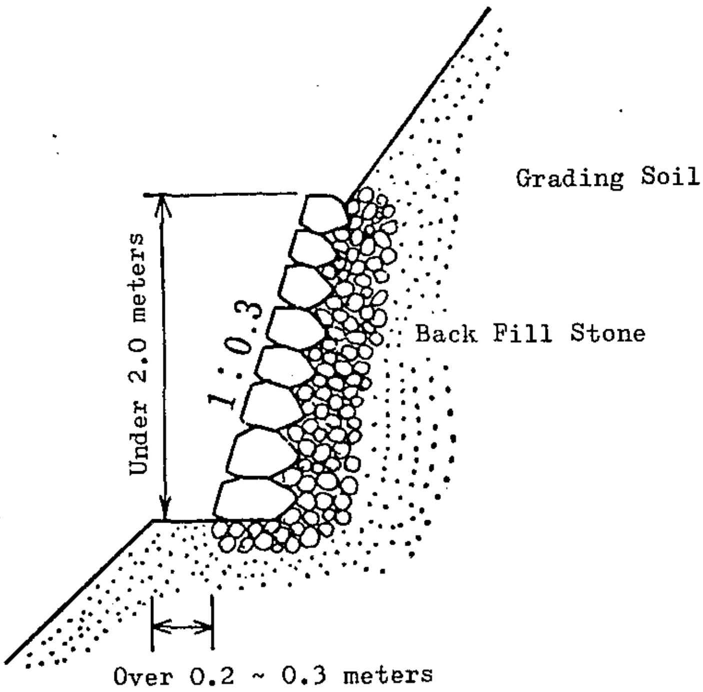


Diagram 3-3 Dry masonry Retaining Work

This work must be executed on rigid foundations with surface slope ratio of 1:0.2 (i.q. vertical = 1, horizontal = 0.2) to 1:0.3 since the own wiehgt is excessive. Additionally, the height must be kept below 3 meters to maintain safety against the earth pressure. Furthermore, joint should be provided every 10 - 15 meters when the overall span exceeds 20 meters to preclude expansion of the damage in case of catastrophe, along with the basic principle to install drainage holes.

Diagram 3-4
Concrete Retaining Work

Concrete Retaining Work

Concrete retaining works are applied when absolute slope stability and rigidity are required in hillsides with potential of slippage generation where other methods cannot be executed due to excessive earth pressure as well as on hillsides with the ease of concrete application. The height should be kept below 4 meters to maintain safety even when foundation works have been accomplised to a considerable extent, since the supportability of foundation layers in collapse sites are uneven, and often accompanied with steep inclines.
The sectional forms are disigned in accordance with the back earth pressure. When the earth pressure is high, the back slope, therefore, should be determined in conformance with the condition of the work site based on the crown width at 30 centimetres and the front slope ratio of 1:0.3.
The rear slope should be right angled or minus slope ratio of 1:03 when the earth pressure is low.
The back filling is provided to iniform and relax the earth pressure on structures as well as to rapidly drain the water infiltrated from the back, and its thickness should be over 30 centimetres.
Additionally, vinyl chloride pipings, etc. are laid in order to drain the water in the back to the front to reduce the pressure.
Expansion Joint provided for the prevention of destruction by temperature change and are executed in the identical manner with those for the masonry work. Additionally, these expansion joints should be halving joints instead of straight joints. Asphalts and Elastites are mainly used for sealing mediums.

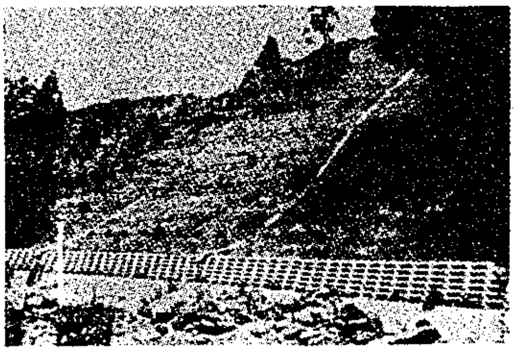


Diagram 3-5 Square Crib Retaining Work

3) Square Crib Retaining

Structures may be easily broken with masonry and concrete works by ununiformed settlement, as well as soil horizon shifts in poor ground with uneven supportability. The square crib retaining work is the method employed in the aforementioned case.
Square cribs are square reinforced concrete bars assembled on the work site into a square and filled with gravel and rubbles.
Concrete work on collapsed hillsides with disproportioned ground bearing power often presents difficulties of material transportation and onsite miding. Therefore, the square contrete bars employed in this method are considered to be beneficial with the ease of transportation as well as the simplicity of execution, requiring only assembly due to being factory products. The sectional dimensions of the square bars are to be considered in accordance with the size of the earth pressure in this method, since the earth pressure is resisted with the weight of the gravel and boulders filled within the cribs. However, individual heights must be kept below 3 meters since the strength of a single square bar is limited. Additionally, retaining effects are known to have been enhanced by providing two rows with clearance in between. Furthermore, protective works are performed at times to prevent the top from becoming demaged by falling rocks.

Concrete Plate Retaining Work

The two types of this work method are as explained in the following. The first is by mounting two or three steps of 1.0 x 0.3 x 0.03 meter concrete plates in the back of concretes piles and refilling this rear side to attain retaining effects upon completion. The latter is by linking 1.0 x 0.3 x 0.03 meter surface plate to 0.25 x 0.2 x 0.03 meter supplementary plate with 0.5 meter vinyle pipes and filling with soil and gravel as illustrated in diagram 3-6.

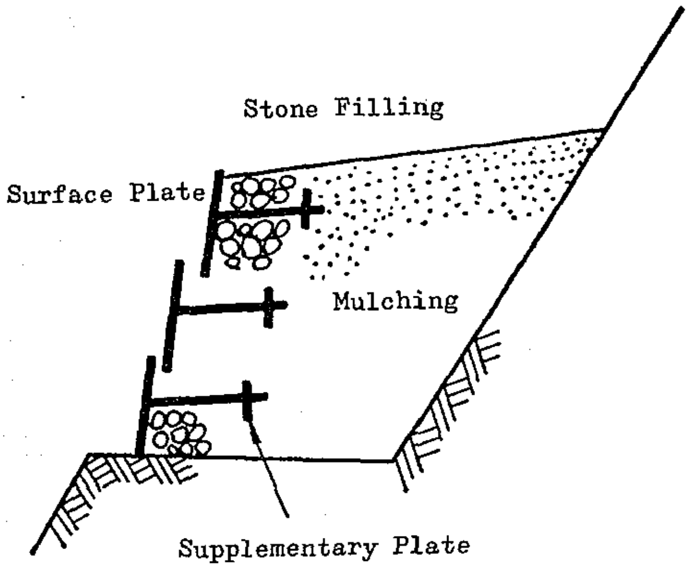


Diagram 3-6 Supplementary Panel Type Concrete Retaining Work

Additionally, this method exhibit features such as the ease of transportation as well as on-site assembly. However, it is important to verify the safety when employing this method since the earth pressure resistance is small compared to other retaining works. The height must be kept below 1.2 meters with 4 steps even with the supplementary panel system, and below 0.9 meter with 3 steps with the standard type. Stability may be further increased by replacing the filling gravel with concrete.

Wire Cylinder (Gabion) Retaining Work

This method is employed on grounds which may be destroyed with retaining work employing concrete and masonry, etc. due to slippage and differential settlement of the gorund. The height must be kept below two meters in order to minimize the damage when the cylinder comprising wires break, since the durability of wires are limited, regardless of diameter or corrosion resistant treatments.
Securing piles are placed every 2 meters to unite the individual cylinder steps in order to prevent slippage. Select rot retarding timber or apply rot prrofing coating on these piles in order to extend their effect over a prolonged period of time.
Additionally, stone filting with mixed diameters stones larger than the size of the wire mesh in order to reduce the porosity and increase the resistance against the settling and shifting of the ground.
Furthermore, at job sites where good quality boulders are readily available, filling materials are easily obtained, with a secondary effect to clear the work site.

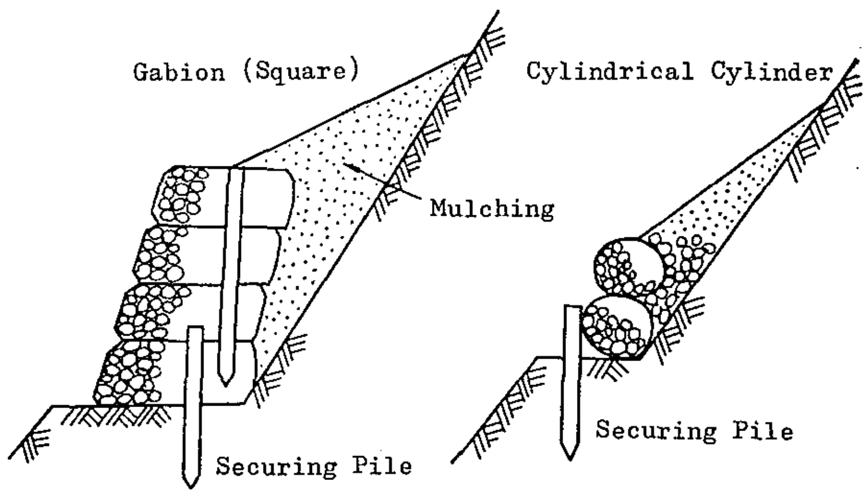


Diagram 3-7 Wire cylinder (Gabion) Retaining Work

6) Fascine Retaining Work

This is a pile of 40 - 50cm long 10cm diameter fascine bundles piled alternately with 10cm thick layer of mulching. This method exhibits increased moisture storage of the slope resulting in early stage growth of vegetation. However, although this method is ideal for execution during the winter in excessive congelation areas, the height must be kept below 1 - 1.2 meter due to the easy rotting of fascine bundles and low earth pressure resistance. Furthermore, execution in surface run-off concentration areas should be avoided since covering soil are easily washed out by surface run-off. The surface incline should be under slope ratio of 1:3, with twigs such as willow, which has good reproductive power from sprout, intermixed in the fascine bundle. Moreover, it is important to plant the soil covering with weeds such as miscanthus for early stage growth of vegetative overlay in order to increase the retaining effect with vegetation.

Fence Retaining Work

Fence retaining work is performed in order to prevent the filling soil from becoming washed out as well as improve the environment of the planting by producing fences filled with soil in the back in the horizontal direction along the hillside. Logs and fascine are used as materials for this fencing. Logs and fascine, though, are only used for temporary measures or when early stage restoration of stability is anticipated due to the poor durability. Piles securing the fence must have a top end diameter over 9cm with a length of 1.5 - 2m. These piles are driven into the hillside in the bisecting direction of the vertical and perpendicular on slope directions as illustrated in diagram 4-9. Piles are driven in this angle since they may be removed or fractured by falling rocks when placed vertically, or reduced in resistance against earth pressure when placed perpendicularly on slope. The standard pile driving depth is over 1/2 - 2/3 the length of the pile with one meter space. Early stage vegetation growth may be attained resulting in improved ground securing effects, by intermixing species with storing sprouting characteristics into the fascine.

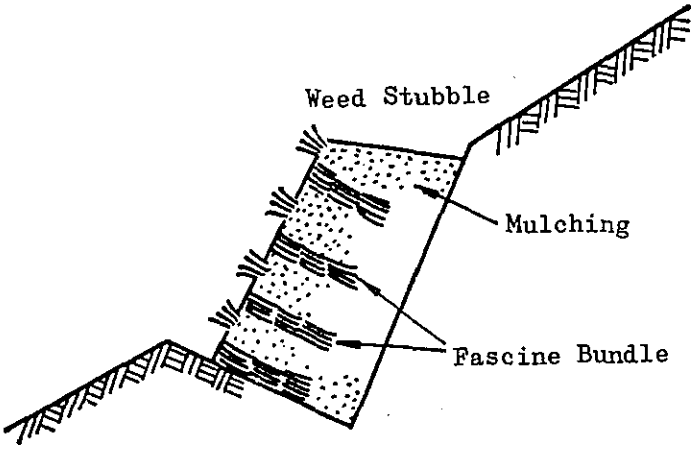


Diagram 3-8　Fascine Retaining Work

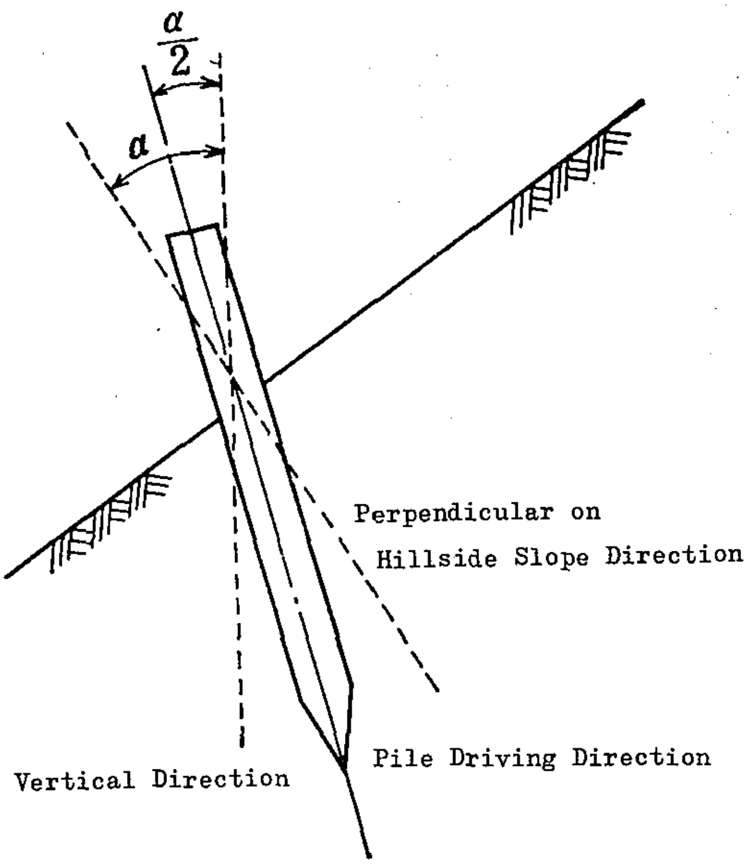


Diagram 3-9　Driving Direction of Securing Pile

3. Buried Work

This method is employed when hillside slope restoration is difficult unless the waste soil is deposited deeply into the sunken sections due to excessive grading soil volume. This work is applied underground in areas where surface structures may be destroyed when the aforementioned soil become shifted with water. Structures are in accordance with retaining works. Additionally, concrete, stone masonry, wire cylinder, fence, and square cribs are designed.
The layout with buried work must be designed where the deposited soil become lower than the angle of repose. Furthermore they must be built rigidly on safe and sound foundation.

4. Drainage Work

Drainage work may be segregated into the water channel work, performed for the collection and drainage of surface water in order to prevent hillside erosions caused by the surface runoffs produced by rain and springs as well as to protect surface structures, and the closed conduit work placed underground in order to drain ground water which soften the soil horizon and cause clod slippage.

(1) Water channel Work

Layouts vary depending on the form of the work-site/topography, but are placed along the concave slopes on the collapsed surface.
The flow section is determined with the catchment area. Calculations to obtain the sectional area, are explained in following Chapter.
The safety factor in hillside channels should be 5, considering the soil, gravel, and stump deposition. Additionally, there are arc, trapezoid, and quadrangle formed sections.
The incline of a waterway must be made constant since soil may deposit in the changing point of gradient resulting in decreased flow sections. The waterway must be split in conjunction with hillside retaining work at changing points of gradient. Additionally, gradient must be reduces in conjunction with hillside retaining work similar to the aforementioned changing points of gradient, for the flow surface become eroded with run-offs when the angles of incline are excessive. The length of a single span should be basically less than 20 meters considering the risks of differential settlement caused by the self load of the

water channel and by slidingdamages. Bed gindle ① are to be provided in places where the overall length exceeds 20 meters.
Waterchannel works may be segregated into stone slastering channel with wet and dry masonry, sodded channels covered with sod, concrete waterchannel, concrete piping, corrugated pipe channel, and wire cylinder channel in accordance with their structural material.

① The Bed Gindle is also called a supporting line, and is a dam formed structure with the top in the bottome of the waterchannel. This structure rectifies the waterchannel gradient to enhance safety as well as prevents damages by precl ding the water from flowing beyond the waterchannel.

1) Stone Plastering Channel

This type of waterchannel have been employed by mankind since ancient times with flow sections in the form of an arc or trapezoid. The two types of this channel are the wet masonry method where the stone plastering secured with concrete, and the drymasonry method where concrete is not employed.
Wet masonry are performed with DOHGOME concrete as the securing agent for the stone consolidation on a foundation with over 20cm back fill in regions where water concentration on hillsides are abundant, resulting in excessive soil washout by run-offs by rainfall, as well as in unstable ground caused by landslides, etc. Dry masonry are performed on back-fills at times in places where nomal water volume is munimam, such as on thetop of relatively steep gradient hillsides or in low water concentration hard soil regions. *Run-off resistance become increased by supporting the* stone consolidation by securing piles into the DOHGOME gravel packed carefully into the back space.

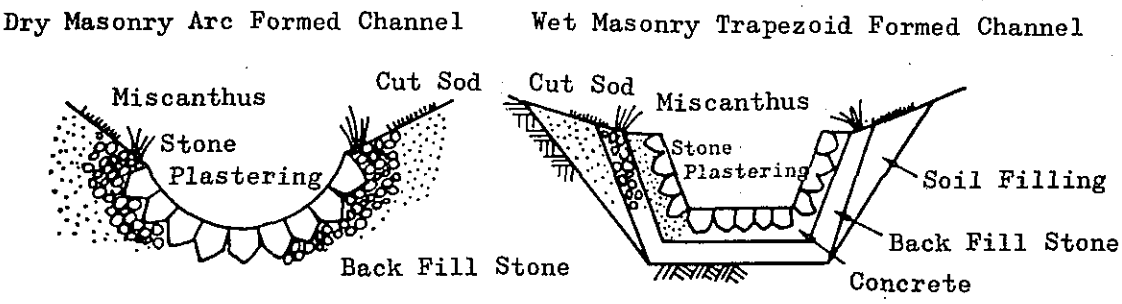


Diagram 3-10 Stone Plastering Channel Work

2) Sodded channel

Sodded channels are employed for branch waterchannel in large scale denuded lands as well as in minor denuded areas with small discharge.

Application of this work is not only simple, but is economical as well when good quality sods are available in the vicinity of the work site. Additionally, this is one of safer methods against differential settlements.

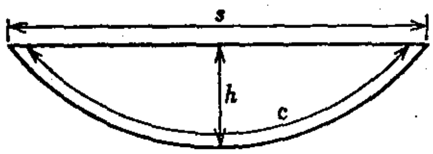
Furthermore, execution must be planned for the season where the growth of the cut sod are rapidly attained. The MEGUSHI or pin stick employed should be comprised with strong sprouted trees in order to attain stability through vegetation. The standard sodded channel form and dimensions should be an arc with 1.2m arc span with 0.3m depth considering the ease of construction and waterway wafety.

The employed sods are to be prepared upon calculation of the area with the equation below.

Diagram 3-11 Sodded Channel

$$A = cl$$

$$C = S + \frac{8h^2}{3s}$$



A: Sod Planting Area

C: Sectional Arc Length

l: Waterchannel Length

s: Waterchannel width (Arc Span)

h: Waterchannel Depth

3) Concrete Waterchannel Work

This type of waterchannel is located with anticipation for efficiency equivalent to wet masonry stone plastering channel work, and are employed for trunk channels. The sectional form of waterchannel produced with this method are either trapezoid, or quadrangle. Bed gindles are added in order to reduce the incline for speed control when abrasion are expected to be generated on the inner surface due to fast run-off speeds.

Standard bottom thickness is over 0.3m with the width at the crown of the sides at 0.15 - 0.2m. Additionally, standard side wall front is slope ratio of 1:0.3 to 1:0.5 with the rear side slope perpendicular or minus ratio of 1:0.1. Slope ratio of 1:0.1 to 1:0.2 it to be placed on side walls when earth pressure is expected to be excessive. Construction of this type of water-channel must be made on rigid foundations since the self load is excessive, with all loads applied to the bottom, and therefore, may become destroyed by differential settlement.

4) Concrete and Corrugated Pipe Waterchannel

This method is employed in places where execution of other methods are difficult because of water, or in areas where concrete cannot be laid on the work site due to excessive run-offs during rainfall, as well as where materials cannot be transported resulting in prohibition of onside concrete application due to the topography. This method is become to be employed more widely due to efficient execution.

Concrete pipe is produced in factory, it is made to place concrete in the form with reinforcing bar, and to compact it by vibrators, and to cure it for some terms.
Corrugated pipe is factory product of steel half-circle and have been employed in many case, since it is lighter than concrete pipe, and is convenient in view of treatment and carriage.
Close attetion must be paid for securing these waterchannel when executing this method since conditions are different from level topography. Additional, the major sources for destruction are differential settlement and erosion of the refilled soil caused by run-offs outside the side walls. Therefore, care should be taken when executing protective works for the foundation in the bottom as well as for the outer sides of the side walls.

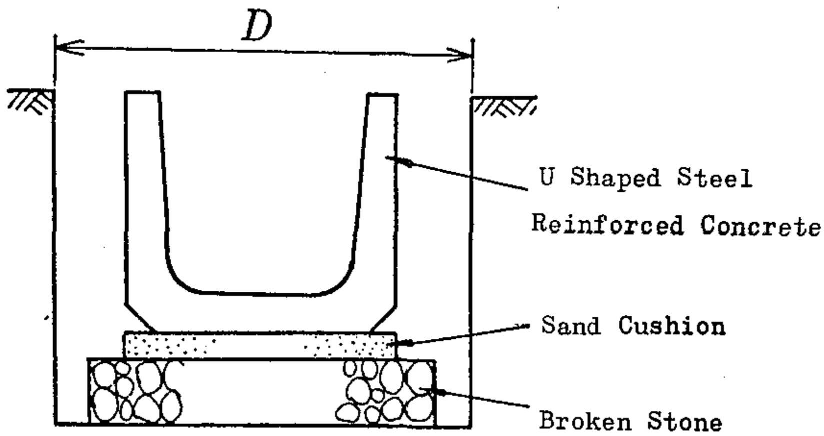


Diagram 3-12 Concrete Pipe Waterchannel Sectional View

5) Wire Cylinder (Gabion) Water Channel
The flexibility of this method is employed in soft soiled areas and in work sited where ununiformed shifting of partial soil may occur.

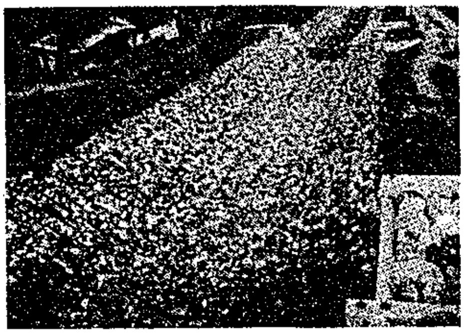


Diagram 3-13 Wire Cylinder (Gabion) Water Channel

Additionally, this method is highly economical in work sites where boulders and gravel employable for fillings are readily available. There two types of wire cylinder waterchannel are the rectangular waterchannel employing rectangle wire cylinders, and the arc formed waterchannel employing the round wire cylinder. The wire cylinders in this method control the channel. Therefore, wire cylinders are secured with securing piles in steep gradient areas, to prevent wire cylinders from being destroyed by the movement of wire cylinders themselves caused with the discharge. Furthermore, close attention should be paid to the execution of the waterchannel bed, so as the collected water become rapidly drained without infiltration.

2) Closed Conduit Work

This is an underground waterchannel provided to guide the ground water which is a cause of landslide generations rapidly out of the area or to surface drainage channels. Designing and method of execution should be determined in accordance with the conditions of spring, sub-surface water and ground water flow. Segregations of this work are made with the materials employed, such as gravel, wire cylinders, fascine, and vinyl chloride pipes.
Gravel covered conduits are widely, used in areas with large volumes of ground water. 5-15cm of gravels are packed as illustrated in the sectional view diagram 3-14, and are then covered with sod or fascine overlay which are topped with soil filling in order to prevent the closed conduit from becoming clogged by soil entry. Drainage effects may be performed over extended periods of time by laying impermeable materials such as vinyl chloride sheets in the bottom to prevent erosions.
Extended effects cannot be expected with the employment of fascine which exhibit poor durability and water catchment, but used when transportation or acquisition of gravel are difficult.
Wire cylinder closed conduits are similarly structured to gravel closed conduits, but exhibit superb preservation effect of a single, stable underground waterway in steep gradient as well as stratum change regions sue piles being driven in approximately every 2 meters to preclude movement.

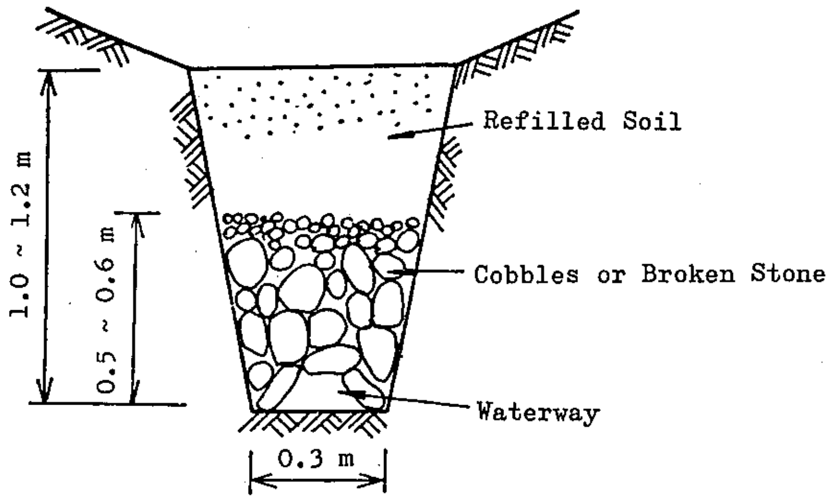


Diagram 3-14   Closed Conduit Sectional View

Closed conduits made of drains comprised with vinyl chloride pipes, etc. maintain effects over extended periods of time even in relaxed waterway gradient regions. However, selection.of types and sizes must be made in accordance with the ground water volumes, soil conditions, and the degree of gradient.

Section 6   Hillside Planging Work

Soil movements on devastated hillsides may be temporarily stopped with the various aforementtioned foundation works. However, though, soil structure which is the base of vegetation growth of such surfaces are poor, and are inadequate for rapid vegetative overlay due to delayed natural entry of vegetation. Structures erected for hillsides foundation works may be destroyed with hillsides reverting back to the original devastated condition when heavy rainfalls or avalanches are encountered prior to the development of the stabilization effect of vegetative overlay.

Following the execution of hillside foundation works, overall replanting should be performed to prevent generation and increase of erosion. Additionally, restoration of the water regulation and conservation effects of forests should be simultaneously considered. Therefore, vegetation methods such as planting on horizontally cut-away steps in hillsides as well as overall replanting are performed. In either case, continued stabilization of the slope with full-grown forests must be considered, starting with grass overlay initially, followed with induction of trees.

1. Sodding Work

This method is applied on denuded collapsed hillside with poor surface soil as well as dry hillsides. The purpose of this work is to improve the environment of trees as well as to disperse and infiltrate surface run-offs and to delay the run-off speed in order to prevent sheet erosion and facilitate the growth of the vegetation.

Depending on the volume of sods employed, this method may be segregated into triple sheet, quintuple, and step sodding work, etc.

0.3–0.5m width horizontal steps are cut out every 1.0–1.5m lineal height from the slope, and the surface slope is executed ratio of 1:0.3 and is covered with cutting sods. Tree is planted in the back of the terrace by filling back with soil.

Vegetatition, growth may be facilitated by applying fertilizers as well as by laying rice straw as the primariry fertilization agent, and moisture preservation. Artificial vegetation blocks and vegetation sacks [1] work are applied in work sites where transportation and acquisition of natural sod are difficult. 1 .

The standard lineal height of sodding works should be 1m up to approximately 20 degrees incline hillsides, and 1.5 - 2m for steeper slopes. The height should be decided in accordance with soil nature. In other words erosions on slopes may be decreased by blocking sandy soil low, and mixed soil such as clayish viscous soil hight.

Terraced sodding work is a term given to sodding works applied continuously with multiple steps on hillsides, which are employed for securing deposited silts in the sunken sections of hillsides as well as spurs. Furthermore, masonry or concrete foundations as well as closed conduits are often used in combination with this work for safety.

Vegetation blocks are compressed and formed mixtures of soil, fertilizers, and cut rice straw planted with plant seeds. Vegetation sacks are meshed sacks filled with soil, fertilizers, and plant seeds.

Either of the two may be intermixed with the most appropriate combination of the aforementioned ingredients in accordance with the soil at the work site.

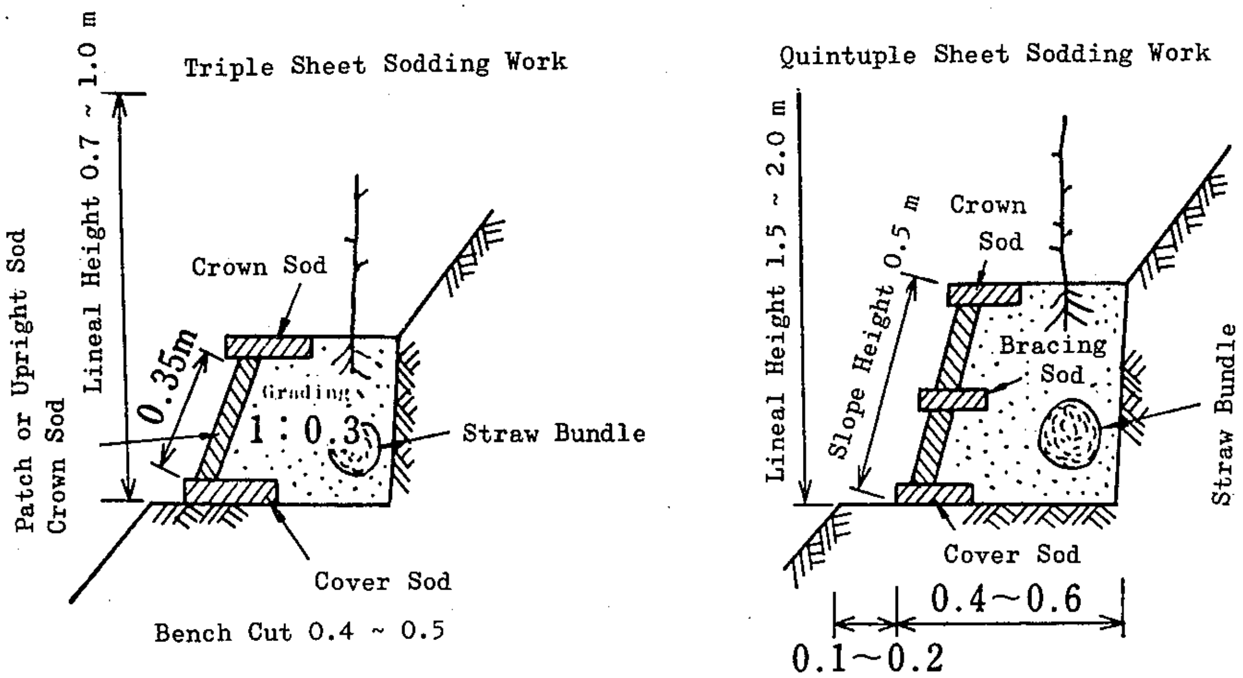


Diagram 3-15 Sodding Work Sectional View

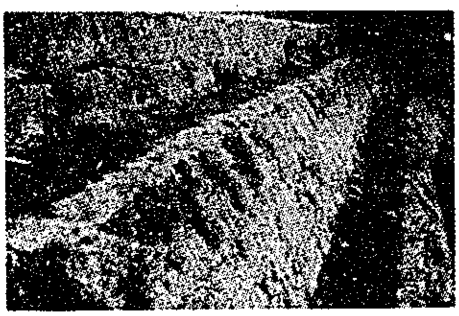


Diagram 3-16 Terraced Sodding Work

2. Simple Terracing Work

This is a form of terracing work which is simpler than sodding work, and is used on work sites with relatively abundant surface soil.
As with sodding work, the objective of this work is to prevent surface erosions by dispersing the surface run-offs on the slope surface

as well as to enhance early stage growth of vegetation with the improvement of the environment by increasing the water infiltration underground. Simple terracing works are applied by simply cutting steps out on hillsides to plant weed stubs or to apply secondary replanting products in strips, or by filling the terraces made of fascine or masonry with soil, as well as by applying secondary replanting products directly on the slope in strips.

Vagetation growth may be enhanced by employing straws for the primary fertilizing agent.

(1) Miscanthus Simple Terracing Work

This work is used in work sites with good soil condition where sodding works are not needed, and are often executed in combination with other treatments. This work is employed in work sites such as on the top of retaining works at the bottome of hillsides as well as where terracing is difficult due to steep incline, with soil adequate for the growth of Miscanthus.

Diagram 3-17 Miscanthus Simple Terracing Work

On hard soiled terrain, the miscanthus is planted in the berm of the terrace with a lineal height of 1.0 - 1.2m and a width of 0.3 - 0.4m cut out from the slope. Additionally, on soft soiled terrain, miscanthus growth may be expected by planting in horizontal strips with a lineal height clearance of 0.5 - 1.0m without cutting steps out from hillsides.

However, the aforementioned standard figures need not be adhered when covering works explained in the following part is to be performed on the slope in between the miscanthus step work.

(2) Sodded Simple Terracing Work

This work is identical to the aforementioned miscanthus simple terracing work with the subsidation of miscanthus with sod. This work is highly economical in work sites where sods are readily available in the vicinity.
Gradient between terraces are increased when terracing works are applied on steep slope hillsides. Therefore, these steep gradient must be mitigated with covering works to protect the slope.
On the other hand, replanting effects may be satisfactorily achieved in deep soil, good soil guality, gentle gradient sites by planting sod directly without terracing.

(3) Stone Simple Terracing Work

This work may not only be facilitated in work sites where boulders, gravel, and rubbles are readily available, but also aid in clearance of work sites. However, this work is not suggestable for employment in severe frost lifting or heavy snowfall regions.

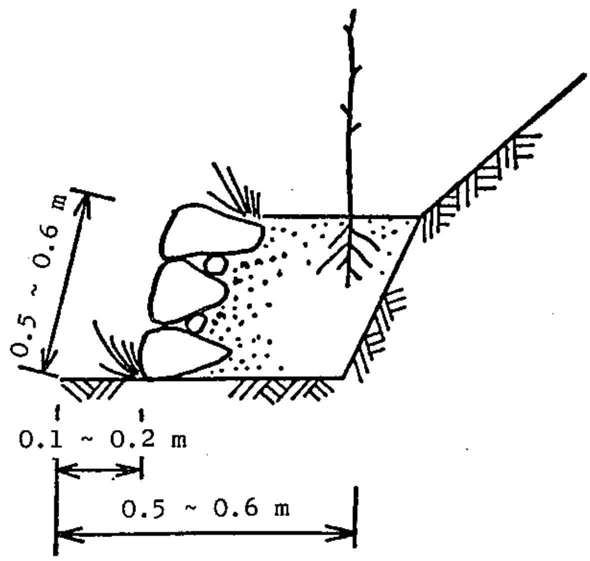


Diagram 3-18 Stone Simple Terracing Work

0.5 - 0.6m width steps are cut out every 1.0 - 1.5m lineal height. Stones are then piled for less than 0.5m height, followed by filling the back with soil. The surface slope should be more than ratio of 1:0.3 for these stone piles considering the safety, with weed stubs such as miscanthus planted on the crown and base for protection. Stones should be pilled in the longitudinal direction considering stability since stability is increased with longer brace length, using hard, weather resistant stones.

4) Fascine Simple Terracing Work

As illustrated in diagram 3-19, this work is performed to enhance the planted vegetation growth by cutting to from so to speak a pot with soil filling in the back of the bascine bundle. This method is employed in places where rapid stabilization of the soil by the early stage growth of weed stubs and miscanthus stubs may be expected since fascine rot rapidly. In other words, the applicable place is where the rainfall is relatively minimal, with the soil being viscous and the gradient gentle, as well as free of surface run-off concentration.

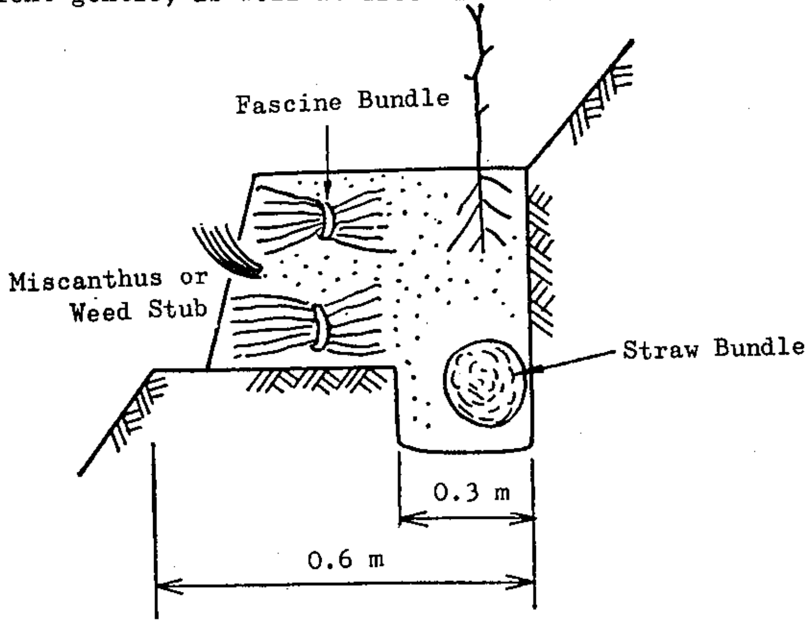


Diagram 3-19 Fascine Simple Terracing Work

1.5m lineal height, 0.8m width steps are cut on hillsides, piled with several layers of 0.1m diameter, 0.4m length fascine bundles until height between 0.3 - 0.5m is attained, and are then finally covered with soil.

Simple Terracing Work with Secondary Replanting Products

These factory manufactured secondary products for replanting work are becoming to be used widely in recent years due to their efficiency for reducing transportation costs as well as cost effectiveness. These products may be segregated into those with soil dressing effects and those without

Those with soil dressing effects are employed in places where natural ground is exposed as well as poor soil conditioned areas. They are mainly comprised with soil intermixed with peat and fertilizers, or organic fibers as the parent material which are then blended with highly germinative power plant seeds with expectations for early stage slope stabilization by the rapid growth of vegetation upon execution. Products which do not exhibit soil dressing effects are mainly cloth and rice straws applied with plant seeds and fertilizing agents, and are used in areas where the sedimentary is deep, exhibiting adequate vegetation growth conditions. The actual execution of this work is nothing more than cutting horizontal 0.5m lineal height ditches on hillsides in order to bury the products followed with earth covering upon completion.

3. Covering Work

Steep gradient slopes may fall or become washed out by rainfall, freezing, needle ice, and wind when left untreated. Works performed in order to prevent afor mentioned falling or washing out and to prevent the washout of planted vegetation as well as to preserve the moisture for the germination and growth of vegetation with overlays are called covering work. Covering Works have been executed with fascine, rice straw, straw mats, an and nets conventionally, but are becoming to be superseded with secondary replanting products possessing effects of both covering and seeding works.

(1) Fascine Covering Work

Fascine covering work is to lay fascine closely horizontally on the slope with wooden cramp and piles driven in to secure.

This method is employed in work sites where fascine is readily procurable as well as where piles may be rigidly driven.

The clearance between the wooden cramp should be lm, to fasten fascine and piles are to be driven into the center and sides of it.

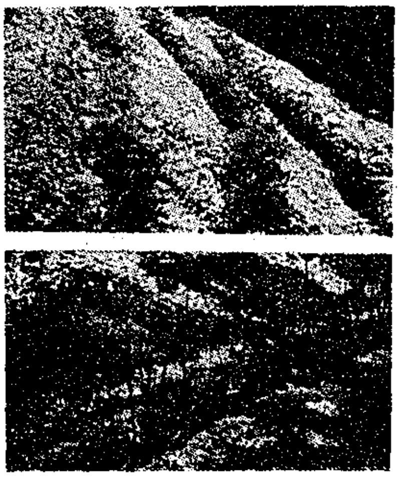


Diagram 3-20 Fascine Covering Work

(2) Straw Covering Work

This method is employed in places where the slope gradient is relatively gentle with easy drying features as well as minimal surface run-offs.

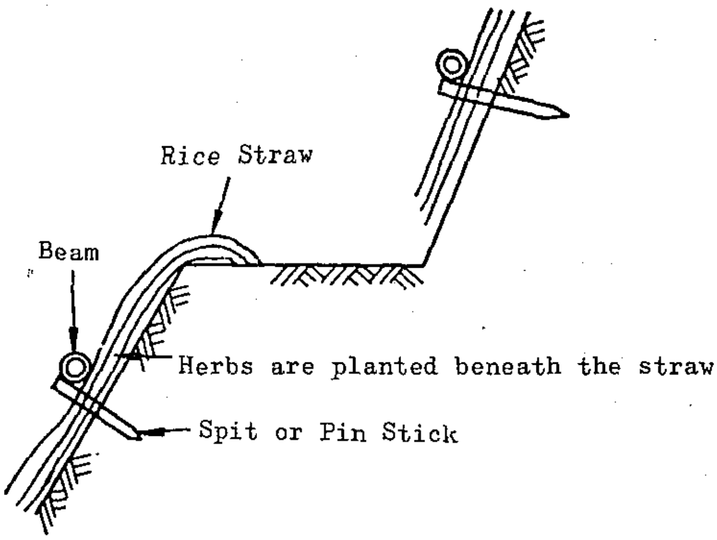


Diagram 3-21 Straw Covering Work

Straws should be secured with ropes, beams, and spit in order to prevent from littering by winds and rainfall. Straws may be superseded with miscanthus in places where they are readily available.

(3) Straw Mat Covering Work

Erosions on light soiled slopes may be enhanced with each succeeded rainfall finally resulting in the collapse of the slope. Additionally, there is highly erodible by frost heaving and needle ice in cold regions. It is therefore beneficial in such regions to cover the soil with rice straw mat after seeding to prevent the aforementioned phenomena. This method is often partially executed in consideration of the dried condition of the slope along with other forms of covering work. It is necessary to secure the mats with ropes and spit.

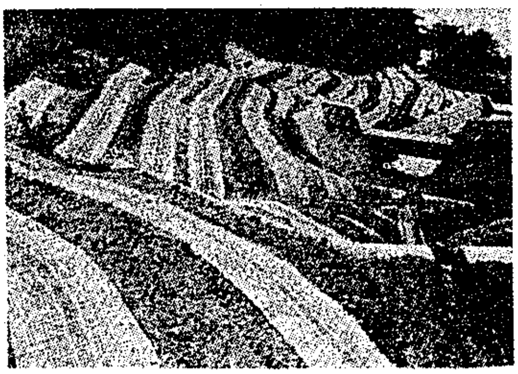


Diagram 3-22

4) Net Covering Work

This method is employed in places where the gradient is excessive and when materials cannot be maintained and secured with other forms of covering work. This work may be segregated into those which are executed in replantable areas and those which are executed in areas where replanting is difficult.

The method employed in replantable areas are accomplished by securing nets applied with seeds, fertilizers, and other organic mediums in order to achieve both seeding and covering work effects simultaneously. The method in areas where replanting is difficult is accomplished simply by covering the overall ground with nets to physically prevent rocks and surface soil from falling. Although surface soil is produced over a prolonged period of time on such surfaces allowing entry of vegetation upon stabilization, plant seeds must be sowed to enhance this effect.

4. Slope Seeding Work

Overall vegetative covering is necessary in order to permanently stabilize the hillsides. The hillside slope is left bare between the steps and planting trees for some time after completion with methods other than the covering work. Early stage overall replanting using trees and weeds must therefore be considered since these bare surfaces are

highly erodible by rainfall, wind, freezing during this period.
Slope seeding works therefore, is a method to sow seeds throughout the slope directly individually or in combination with other works to vegetate the ground with the germination and growth of vegetation.
Methods such as sowing seed and fertilizer mixture into ditches and covering with soil, or by overall sowing on hillsides which are then covered with straw and straw mats are currently employed. Additionally, seed and fertilizer mixture are being sprayed on slopes with pump, and then adhesives such as asphalt emulsion sprayed over in order to prevent washouts of sprayed seed and fertilizer. Furthermore, seeding is accomplished by helicopters in distant areas where material transportation is difficult, as well as when large devastated areas must be replanted in a short period of time.
The seeds of trees and grasses mixture are comprised of seeds with different characteristics, and the blending proportions are adjusted in accordance with the germination periods as well as initial growth conditions. Additionally, the seed quantity is increased or decreased in accordance with the number of individual growth per area unit.

Characteristics of trees and grasses for slope Seeding Work

1) Germination and Initial Growth
   Grasses employed for slope seeding work must germinate simultaneously within a short period of time from seeding and exhibit rapid initial growth in order to cover the unstable surface soon after the completion of hillside work.

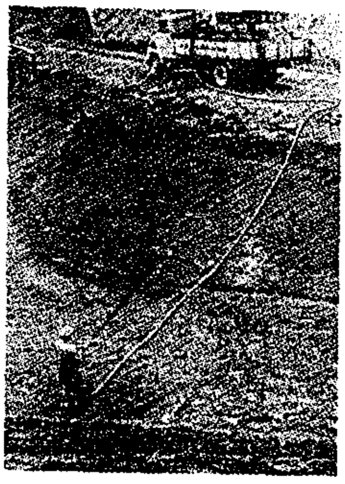


Diagram 3-23 Seeding Work with Pump (Spraying Work)

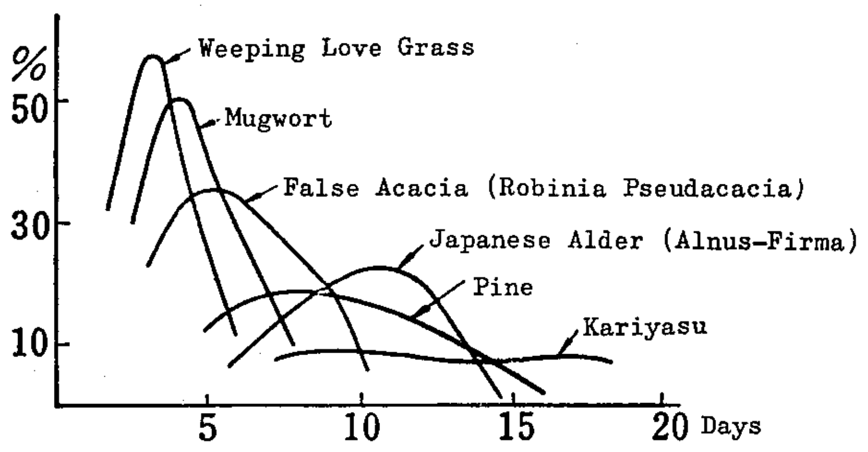


Diagram 3-24 Germination Conditions of Grasses for Hillside Planting Work

Conditions of germination are highly dependent on the environmental conditions of the particular time. Under normal conditions, plants such as Weeping Love Grass, Kentucky 31 Fesk, clover, and Mugwort sprout after 2 - 3 days from seeding, and Creeping Red Fesk, as well as Bermuda Grass sprout within a few days. Conventional perennial herbs which exhibit superb continuosity and applicability devastated lands exhibit delayed and ununiformed germination periods. Many leguminous plants such as Acacia among ligneous trees sprout within a few days and exhibit improved initial growth when germination inprovemen treated.

2) Ease of Breeding

Good quality seeds with strong germinative power must be promptly obtained in large volumes, since abundant vegetation are desired to sprout and grow within a short period of time from seeding during replanting of devastated land. Imported pasture generally exhibit these features among herbs. Additionally, Miscanthus, Mugwort, and Giant Knotweed exhibit good features among perennial herbs, as well as False acacia, Japanese alder (Alnusjaponica and Alnus firma), Oleaster, and pine also exhibit identical features among ligneous plants.

3) Forms of Growth

Forms, periods, and heights of growth are one of the essential conditions to be considered for the selection of the plant to be employed for replanting.

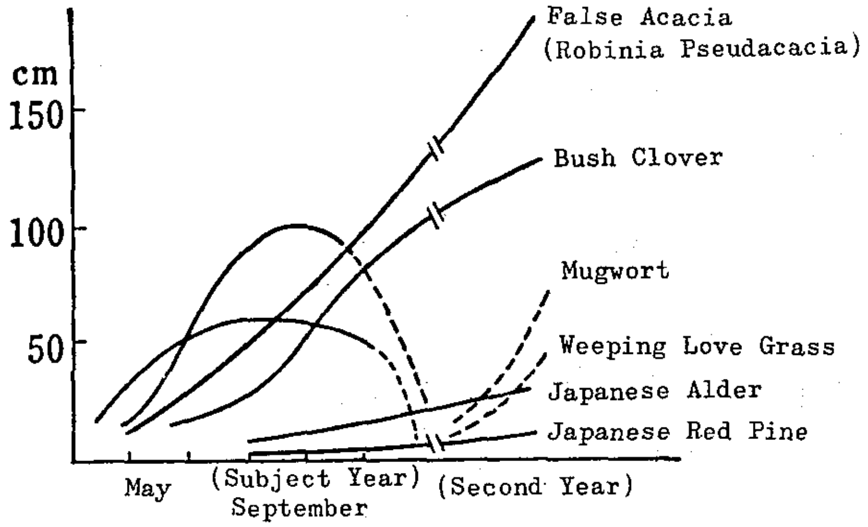


Diagram 3-25 Initial Growth of Plants for Replanting

Growth forms may be segregated into plants which grow in branching at roots fasciculate form such as vegetative plants (e.g. rice and Cyperus *microiria*), procumbeats or creeping (e.g. sod), erect type (e.g. mugwort), and rhizome plants (E.G. Kentucky 31 Fesk). Procumbeats and rhizome plants exhibit the greatest slope stabilization among the aforementioned. Additionally, there are winter grass type which grow during the colder spring and fall seasons as well as summer grass type which grows well during the hotter summer seasons as characteristics for growth periods. Seed mixtures are blended mainly with the former of the two when planting in the spring or fall or in colder areas, and the latter during the summer or in warmer areas.
There are perennial and therophyte herbs among plants. Therophyte plants not only hamper to the growth of other plants by oppressing with its rapid initial growth, but also exhibit rapid decrease in surface stability when they decline. Therefore, replanting works must be performed employing perennial herbs.
As far as the height of growth is concerned, wild grass such as miscanthus and mugwort grow tall, and oppress other vegetation when they begin to grow densely. Kentucky 31 Fesk and Weeping Love Grass among imported species grow relatively tall and produce vegetative overlay in a short period of time. However, close attention should be paid the seed quantity and mixture proportion of these plants per area unit since they may overgrow and oppress other vegetation. Procumbeats such as Bermuda Grass, Clovers,

and sods grow low on the ground and do not oppress or hamper the growth of other vegetation.

4) Other Features

Desirable features of grass and trees for slope seeding work aside from the aforementioned are good growth on infertile and arid land, improvement of soil fertility through root module bacteria function and desease resistance.

Strip Seeding Work

This is a method applicable for relatively gentle gradient places where a mixture of seed and fertile soil are manually sown in ditches cut away on hillsides or steps. However, this method may also be applied on hillsides with fairly steep gradient since sowing seeds are secured in the cut ditches.

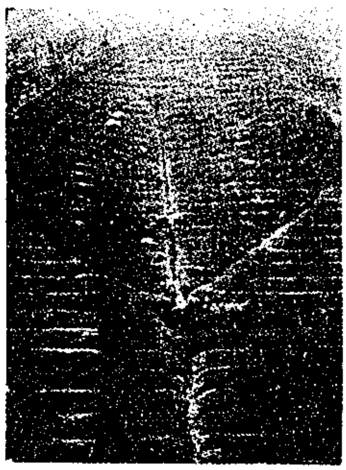


Diagram 3-26 Strip Seeding Work

Procedures most applicable and economical should be selected with the ditch depth and width in consideration, since the amount of soil investment differ depending on the soil condition of the work site.

Slope Seeding Work

This is a method applicable for relatively gentle incline slopes with good soil condition. However, this method may also be applied on steep slope hillsides when protective measures such as covering work

are executed immediately seeding for the prevention of seed washouts as well as for the preservation of moisture for germination.
This work may be performed efficiently by spraying with pumps when the work site can be reached with vehicles. In such case, there are methods where the seeds, fertilizers, and adhesives are sprayed simulatneously, and where they are sprayed individually.
The seeding quantity varies depending on the condition of the land as well as the type of seeding mixture, and therefore, should be determined with the anticipated numbers of germination of 3,000 to 10,000 per square meter and the rate of germination in consideration.

Section 7 Planting Work

Planting works are executed for the early stage restoration of the disaster prevention effects of the forest which are lost on devastated lands with the growth of trees by planting seedlings.
The conditions for the growth of trees may be prepared to a certain extent with the various aforementioned hillside works. However, though, soil nature of such work site normally exhibit far poorer soil nature compared to normal plantation even after the execution of hillside works. Therefore, the soil nature, topography, and climate of the work site as well as the vegetation in the vicinity should be closely studied when making determinations for the planting plan. Improvement measures such as soil amendment and fertilization must be applied in order to be able to expect positive early stage growth and maturity of the vegetation.

1. Planting Plan

Land Classification

Lands are classified in accordance with the land conditions at the work site in order to select the most applicable species and planting quantity of vegetation. Planting plans for the individual regions are as described in the following.
Important trees may be planted when risks for flooding as well as silt wash outs are not evident since such lands exhibit good soil conditions comprised with silt deposited by fixing of channel during the formation of the stream.

Silt deposit part within collapse are formed with silt produced by surface fall-offs from above as well as by soil generated with grading works. Therefore, soil conditions in such land are relatively good, and superb tree growth may be expected.
Denuded zones within devastated lands lack surface soil and have bad conditions such as steep gradient, dryness, and frost heaving. Therefore, hillside planting plans must be designed carefully with these matters in consideration. Additionally, improvement measures such as fertilizing, soil dressing, and mixed planting of soil improving trees must be taken progressively in order to facilitate the development of vegetation.

Tree Species for Planting

Tree species are selected in accordance with the aforementioned land classification, based on the "appropriate tree for the appropriate soil" principle. However, though, it is required that the planted species fulfill the following conditions:

1) Abundant growth and thrift.

2) Broad and deep rooting with large soil securing ability.

3) Sterile soil tolerance

4) Strong resistance against negative factors such as aridity, frost, and insect damage.

5) Those which soil improvement effects may be expected

Generally broad leaved trees such as Japanese alders, leguminous plants, and willows exhibit the aforementioned features. However, though, pine tree which is coniferous is also widely employed. Pine trees have been conventionally used widely as the principal forest crop.

(1) Principla Forest Crop
Japanese Red Pine, Japanese Black Pine, Pinus Rigida, Yezo Spruce, White Fir, Japanese Cypress, Zelkova Serrata

(2) Soil Improving Rree
Japanese alder, Mountain Aldes, HIMEYASHABUSHI, (Alnuspendula) Wax-Myrtle (Myrica rubra), willow, Acacia, ITACHIHAGI (Amorpha frution a kind of Lespedeza bicolor), Oleaster, Deutzia (Deutzia crenata)

Furthermore, trees differing in characteristics should be mix-planted in order to reduce various hazards for the development of a highly resistant forestes described in the following.

1) Shallow and deep rooted trees.

2) Principal forest crops and soil improving trees.

3) Coniferous and broad leaved trees.

4) High and low growing trees.

Planting Quantity

Planting quantity varies depending on the species, planting method, gradient of the planting site, and the soil conditions, but should be limited to the standard of 3,000 - 5,000 trees per ha. in good soil condition areas such as soil deposit part within hillside landslide as well as in stream bed, and to 8,000 - 10,000 trees per ha. in poor soil condition areas such as denuded part within hillside landslide. Planting quantity of soil improving trees does not vary with the principal forest crop, but is required to pay close attention to the layout and number of mix-planting, since soil improving trees exhibit rapid initial growth, and therefore, may be oppres the principal forest crop.

2. Planting and Care

(1) Planting

Healthy seedlings with good surface and root system balance should be selected for erosion control planting dur to the poor soil conditions of work site. Additionally, close attention should be paid to prevent from damaging the seedlings during digging out, temporary planting, and transportation.

Seedlings should be planted somewhat deeply in a largely dug out planting hole with the application of soil dressing and fertilizer as deemed appropriate. On the contrary, seedlings must be planted high in low damp ground or in high ground water areas to prevent rainwater accumulation in the planting holes.

(2) Care

Planted trees must be protected with straw litter around the bottom of the trunk in order to prevent desiccation along with weeding until they survive and commence to grow. Additionally, close attention must be paid to the opperssion against the principal forest crops when mix-planted with soil improving trees. This is particularly important when light demanding trees such as pines are used for the principal forest crop. In such case, the number of salvage cutting frequencies needs to be increased for frequent removal. Furthermore, additional fertilization should be performed to facilitate growth when found to be poor. Replanting should be performed rapidly when bare ground surface caused by dead standing trees are found since devastation may expand again from such ground. Moreover, partial foundation work damages must be immediately restored since such conditions may result in excessive disasters.

CHAPTER IV TORRENT WORK

Section 1 Basic Hydraulics for Torrent Work Disigning

1. Hydrostatic Pressure

(1) Hydrostatic Pressure

Rest water which is not flowing is called static water. The pressure of the weight of the water under the static condition is called the hydrostatic or hydraulic pressure. This force is uniform on the surface, and the total resultant of force effecting the entire plane is called the overall hydraulic pressure.

1) Intensity of Hydrostatic Pressure

Hydrostatic pressure is expressed per unit areas since the force is distributed on the plane. The following equation is derived when the hydraulic pressure is uniform at any points on plane A, with the overall hydraulic pressure is P and the force of the water is p:

$$p = \frac{P}{A} \qquad (4\text{-}1)$$

Total hydraulic pressure is expressed in kg, t and other hydraulic pressures are expressed with unit kg/cm^2 and t/m^2, etc. The overall hydraulic pressure effecting a certain plane may be considered as a concentrated force equivalent to the hydraulic pressure effecting the plane. Therefore, it is necessary to define the effecting point of the overall hydraulic pressure as well as its strength.

2) Hydrostatic Pressure Characteristics

Hydrostatic pressures effect the plane vertically. Furthermore, the hydrostatic pressure p is proportional to the depth of the water h. Therefore, with the unit weight① of the water as w; it may be expressed by the following equation.

$$p = wh \qquad (4\text{-}2)$$

Additionally, the hydraulic pressure on a certain point in the water acts constant force in all directions. (Diagram 4-1)

*① Weight per cubic unit.

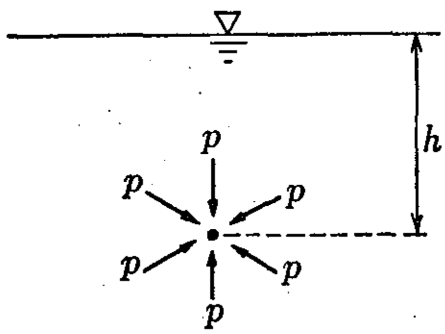


Diagram 4-1 Hydraulic Pressure On A Certain Point in the water

(2) Hydraulic Pressure Effecting A Level Plane

1) Hydraulic Pressure On A Horizontal Plane

The intensity hydraulic pressure acting on horizontal plane such as the bottom of a container is uniform at any point on this plane. Therefore, the overall hydraulic pressure P may be derive from the following equation where the depth of the water is h, whereas $p = wh$, and the area as A:

Equation $P = pA = whA$ (4-3)

The point where the overall hydraulic pressure effects this surface is at the center of figure①. (Diagram 4-2).

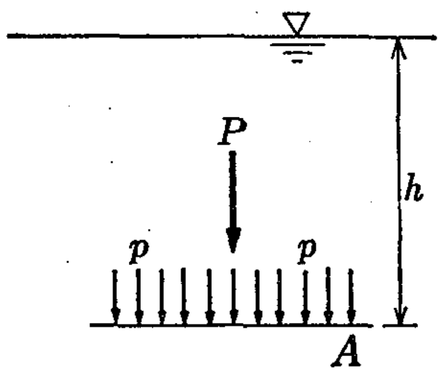


Diagram 4-2 Hydraulic Pressure on A Horizontal Plane

① Center of gravity on a plane figure.

2) Hydraulic Pressure on A Vertical Plane

Hydraulic pressure effects a plane perpendicularly and is proportional to the water depth. Therefore, the distribution of the hydraulic pressure effecting the rectangular zone of the perpendicular height h becomes ΔABC as illustrated in daagram 4-3. Therefore, the overall hydraulic pressure P is described by the following equation with the width of this zone as b.

equation $$P = \frac{1}{2} wbh^2 \qquad (4\text{-}4)$$

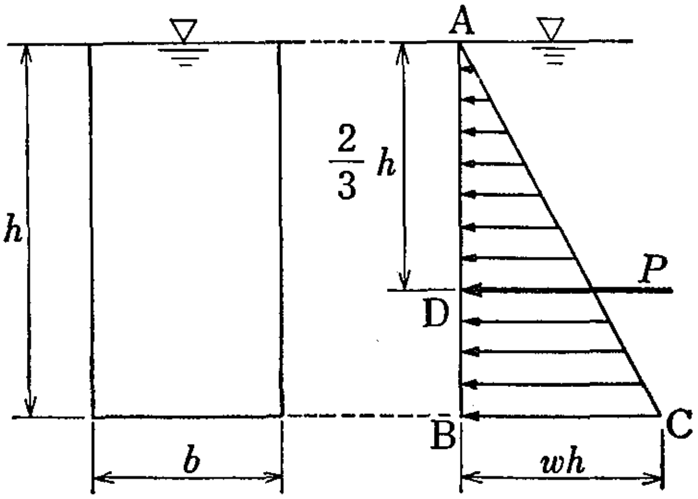


Diagram 4-3 Hydraulic Pressure on A Vertical Plane

The water depth at the effecting point D is 2/3 h since the line of application line of the overall hydraulic pressure P works its way vertically towards the plane AB through the center of figure of the ΔABC.

3) Hydraulic Pressure on A Sloped Plane

The distribution of the hydraulic pressure strength effecting a sloped plane AB with gradient incline 1: n as illustrated in diagram 4-4 becomes ΔABC with $\angle B$ as a right angle. Since $AB = h\sqrt{1 + n^2}$, = wh at this point, the overall hydraulic pressure P may be derived from the following equation with the width of the area as b.

equation $$P = \frac{1}{2} wbh^2\sqrt{1 + n^2} \qquad (4\text{-}5)$$

The water depth at the (effecting point D is 2/3 h since the line of the application of the the overall hydraulic pressure P works its way vertically towards the sloped plane AB through the center of figure of the ΔABC.

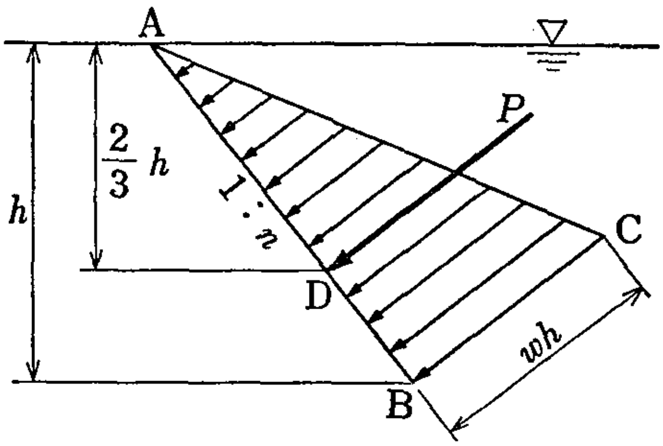


Diagram 4-4 Hydraulic Pressure on A sloped Plane

2. Stream Velocty, and Movement of the Sand and Stone

(1) Basic Characteristics of the flowing water

1) Flow area, wetted Perimeter, and Hydraulic Radius

The movement of water is called flow. The cross section of the channel perpendicular to the direction of the flow is called the transverse channel section, and the area or the portion of the transverse channel section with water is called the flow area (or cross-sectional area of flow). Additionally, the length of the transverse channel section contacting the water is called the wetted perimeter.

Furthermore, the result derived by dividing the flow area A by the wetted permeter P is called the hydraulic radius R. The following equation is the formula for the aforementioned:

equation $R = \frac{A}{P}$

In Diagram 4-5(b) $A = h(b + nh)$

$$\left.\begin{aligned} R &= \frac{A}{P} \\ A &= h(b + nh) \\ P &= b + 2h\sqrt{1 + n^2} \end{aligned}\right\} \quad (4\text{-}6)$$

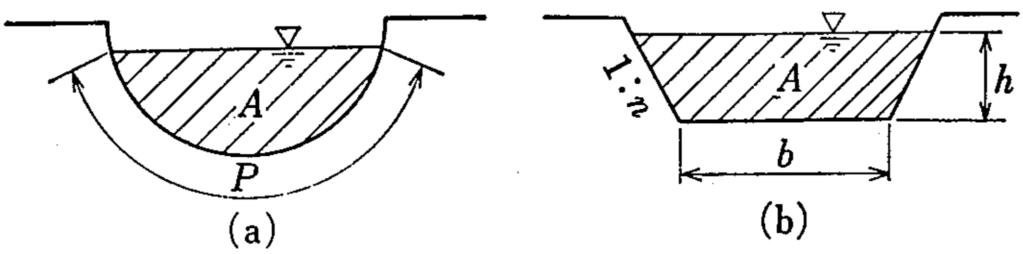


Diagram 4-5 Flow area, Wetted Perimeter and Hydraulic Radius

Flow area is expressed in units of m^2 or cm^2, whereas the wetted perimeter and hydraulic radius are expressed in units of m or cm.

2) Velocity and Discharge

The water in an open channel ① flows from a higher elevation to a lower elevation. The speed of this flow is called the flow velocity. This flow velocity is expressed as the flow distance per a unit time. The flow velocity v flowing the distance L within the time t may be derived from the following equation, and is expressed in units such as m/s and cm/s.

equation $$v = \frac{l}{t} \qquad (4\text{-}7)$$

Generally, this flow velocity differs at every point of the flow area. Therefore, the average flow velocity for the overall flow area is considered, and is used as the average flow velocity of that particular flow area. Additionally, the volume of water flowing through the flow area within that time is called the discharge. The following equation may be derived with the average flow velocity as v, the flow area as A, and the discharge as Q.

equation $$Q = vA \qquad (4\text{-}8)$$

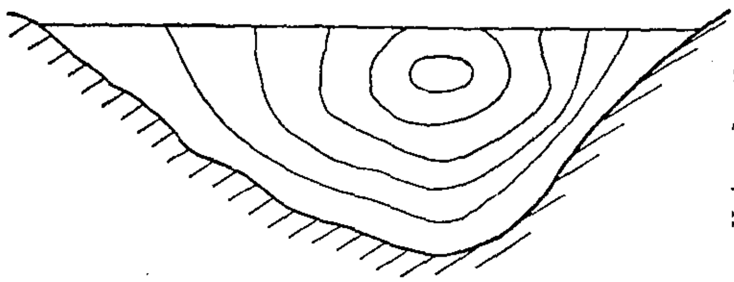
The discharge units are expressed in m^3/s and l/s, but also may be expressed in t/s since a volume weight of water is $1t/m^3$.

① Open channels are water ways such as strea[illegible] ivers, and artificial canals possessing free water surface [illegible] with the atmosphere.

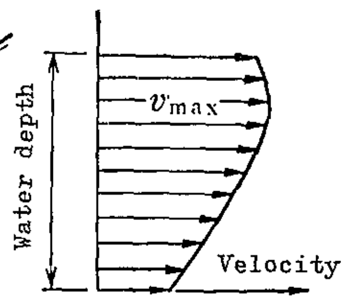
(2) Velocity Measurement

1) Velocity Distribution in an Open channel

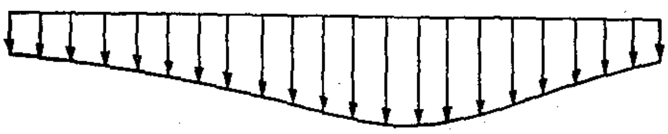
The velocity at various points of transverse channel sections is not constant. This inconsistency is due to effects of the roughness which express is the roughness of the waterway walls, the shape of the transverse channel section, channel sinuosity, and the depth of the water. Diagram 4-6(a) illustrates the distribution of the flow velocity at the transverse channel section as a flow velocity contour curve. The flow velocity generally become greater further away from the channel sides and bottom. This phenomenon is the resultant of the reduced effects of friction with the aforementioned sides and bottom. Therefore, the maximum velocity Vmax is generated at a point slightly below the surface in the vicinity of line of maximum depth. Additionally, the surface flow velocity is smallest along river banks as illustrated in diagram 4-6(b), and increases further distance away from river banks until it becomes greatest in the vicinity of line of maximum depth. Furthermore, the curve which describes the flow velocity distribution on a perpendicular line through a certain point of the transverse channel section is called the vertical flow velocity curve. The vertical curve in the vicinity of line of maximum depth generally becomes similar to that illustrated in diagram 4-6(c). Hereby, the maximum flow velocity vmax is generated 0.1h - 0.4h beneath the surface of the water, and the average flow velocity v is generated at a depth of 0.5 - 0.65h from the surface.



(a) Velocity Contour Curve



(c) Vertical Velocity Curve



(b) Surface Velocity Curve

Diagram 4-6 Velocity Distribution

2) Velocity Measurement with a Current Meter

A current meter is a device used to measure the flow velocity. The measurement is accomplished by lowering a propeller into the desired depth of the water current in order to count the number of revolutions within a specified time. The flow velocity may be derived from the following equation since this equation is generally applicable to express the relation between the number of revolutions and the velocity of flow.

equation $$v = aN + b \qquad (4\text{-}9)$$

Note: v: velocity (m/s), a,b: constants,

N: number of propeller revolutions per second.

*a and b values are the exclusive constants of the current meter and should be primarily derived through experimentation.

Current meters are available with cap form propellers with rotating shafts perpendicular to the flow, and thos illustrated in diagram 4-7 have with shafts parallel to the flow.

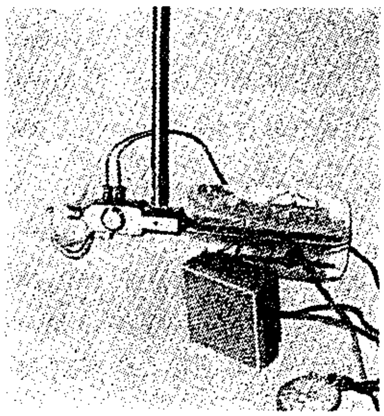


Diagram 4-7 Current Meter

Transverse channel sections are segregated with perpendicular lines for transverse survey in fairly large waterways with large discharge as illustrated in Diagram 4-8, in order to derive the average flow velocity in the individual segregated sections through in equation with the velocity measurements taken at several points on the perpendicular line running through the center of these sectors.

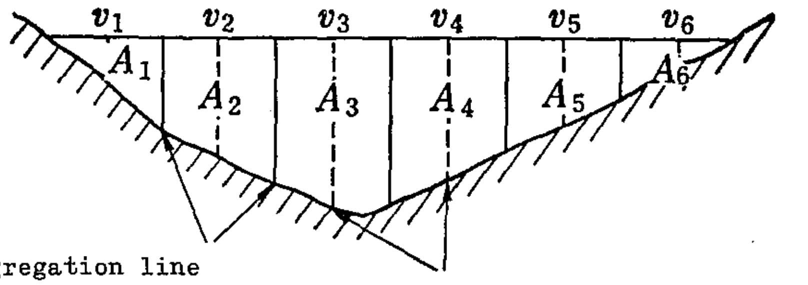


Diagram 4-8 Measurement of Water Channel Section

The flooweing equations are available for deriving the average velocity of the segregated sectors when the velocity in depths 0.2h, 0.6h and 0.8h from surface are v0.2, v0.6 and v0.8, respectively, with the depths of the perpendicular line running through the center of the segregated sectors at h. The following are the applicable equations:

$$\left.\begin{array}{lll} 1) & \text{1 Point Method (equation)} & v = v_{0.6} \\ 2) & \text{2 Point Method (equation)} & v = \frac{1}{2}(v_{0.2} + v_{0.8}) \\ 3) & \text{3 Point Method (equation)} & v = \frac{1}{4}(v_{0.2} + 2v_{0.6} + v_{0.8}) \end{array}\right\} \quad (4\text{-}10)$$

Generally, the 2 Point Method which is relatively simple with high accuracy is used. When particularly accurate values are required, vertical velocity curves are drawn for the individual section to derive the area surrounded by these curves and the vertical axis and to divide this by the depth to derive the average velocity of each section.

The average velocity of the overall channel section is derived by dividing the discharge obtained with the "Velocity method" explained in the following "Discharge Measurement" by the overall flow area.

3) Velocity Measurement with Floats

This is a method where the velocity is derived by equation $v = \frac{l}{t}$ based on the time measured for a float to float downstream for a certain distance. Among the various floats available, there is the surface float which floats on the water surface and the pole float provided with a weight to maintain an upright position in order to measure the average velocity of the surface and underwater currents.

(3) Mean Velocity Formula

Although various formulas are available to derive the mean velocity, it is best represented by the Chèzy formula described below:

$$v = C\sqrt{RI} \qquad (4\text{-}11)$$

Where; v: mean velocity within the flow area (m/s), C: Velocity coefficient, R: hydraulic radius(m), I: water surface slope.

Various empirical formulas are available for deriving the velocity coefficient C:

1) Bazin's Old Formula

equation

$$C = \sqrt{\frac{1}{\alpha + \frac{\beta}{R}}} \qquad (4\text{-}12)$$

Where; C: velocity coefficient, R: hydraulic radius (m), a, β: coefficient of roughness

Generally, $\alpha = 0.0004$ and $\beta = 0.0007$ are applied for torren streams. Details of coefficient of roughness are described in Chart 4-1.

Chart 4-1 Coefficients of roughness for the Bazin's Old Formula

Classi-fication	Channel	α	β
I	Cement coated or plane finished wood channels.	0.00015	0.0000045
II	Smooth surfaced cutting stone, brick, or unfinished wood channels.	0.00019	0.0000133
III	Rough stone or stone pitching channels.	0.00024	
IV	Natural earth and stone channels.	0.00028	0.000350
V	Channels washing down rubbles and rough gravel.	0.00040	0.000700

2) Bazin's New Formula

equation

$$C = \frac{87}{1 + \frac{r}{\sqrt{R}}} \qquad (4\text{-}13)$$

Where; r: coefficient of roughness

Generally, r = 1.75 is used for torrent streams. Details of coefficient of roughness are described in Chart 4-2.

Chart 4-2 Coefficient of roughness for the Bazin's New Formula

Classification of Channel	Smooth cement coated or plane finished wood channels.	Concrete, brick, or rough wood channels.	Rough stone masonry or rough brickwork channels.	Uniformed soil channels.	Normal soil channels.	Rough soil channels.
γ	0.06	0.16	0.46	0.85	1.30	1.75

(4) The critical Velocity and the equilibrium Slope of Gravel

The critical Velocity of Gravel

The current tends to impact and wash off the gravel on the streambed. In turn, the gravel tends to resist this force by the friction with the streambed. The larger the friction at this point, the longer gravel remains, but gravel is washed off when this friction is small. The magnitude of this impact force to washout the gravel is proportional to the square ($*^2$) of the velocity. Therefore, the movement of the gravel is wholly contingent on the velocity. This is why the maximum velocity for the gravel to remain on the streambed is called the critical Velocity of the gravel. The following is the simplified formula to derive the aforementioned: equation

$$v_g = K\sqrt{b} \qquad (4\text{-}14)$$

where; vg: Critical Velocity of the Gravel (m/s),

k: Constant 3.7 - 5.3/average 4.5

b. The length of gravel in the direction of the flow(m).

Assuming that the streambed is comprised of layers of packed gravel, the flowing water tends to wash these gravel layers with a somewhat leveling force. This force is called the tractive force and becomes larger with an increased hydraulic raulic radius and water surface slope. The velocity becomes larger in accordance with equation (4-11) when the hydraulic radius and the water surface slope are large. Therefore, the tractive force too, is closely related to the magnitude of the velocity.

2) Equilibrium Slope

The velocity of flow decreases when gravel is mixed in the flowing water.

Therefore, when the containing gravels of various sizes reaches a certain point, gravel on the streambed with critical velocity smaller than the speed of the flowing water is washed away.

Since the velocity becomes smaller at this point, washed down gravel with a critical velocity larger than the speed of the flowing water settle down on the streambed. As previously described, the flowing water not only washes away gravel, but settles gravel also. The strembed becomes eroded when the volume of the washed out gravel is larger than the settlement, and sand depositting occurs when the washout is smaller. Furthermore, the streambed slope remains the same although the gravel may be changed when the aforementioned both volumes are equal.

This unchanging slope is called the equilibrium slope. In order to derive this, it becomes;

$$C\sqrt{RI} = vg = K\sqrt{b}$$

when considering equations (4-11) and (4-14) to be equal.

With both sides squared, it becomes;

equation $$C^2RI = v_g{}^2 = K^2b \qquad (4\text{-}15)$$

Therefore, the slope l where the gravel with the diameter b becomes stabilized is described by the following equation:

equation $$I = \frac{K^2b}{C^2R} = K'\frac{b}{R} \qquad (4\text{-}16)$$

Where; $K' = \frac{K^2}{C^2}$

Generally, the discharge is less and the size of the gravel on the streambed is larger in the upstream compared to the downstream. Therefore, the equilbrium slope is steep in the upstream and relaxed in the downstream as described in Equation (4-16). But when observed on separate points, the equilibrium slope varies due to the states of gravel intermixture and discharge variation.

3. Discharge Measurement

When executing or designing stream work, it is necessary to know the discharge of the stream both for normal and particularly for flood conditions. The following are the often practiced methods among the various discharge measurement or approximation methods:

(1) Velocity Method

This is a method where the velocity is derived with the product of the measurement taken of the mean velocity and the flow area.
The desirable measurement point is where the channel is straight and the channel width and depth are constant. The velocity is measured with the most compatible method for the condition of the stream and the purpose of the measurement. The flow area is to be derived by cross sectional survey of the channel.
For streams with broad streambeds and large, the cross section of the stream is segregated into several section as illustrated in Diagram 4-8 in order to derive the cross sectional area and the mean velocity individually. Then, the discharge for the individual sections are derived with the product of the cross sectional area and the mean velocity.
These are then summed to obtain the total discharge of the stream.
The following equation describes the above as a formula:

equation $$Q = A_1v_1 + A_2v_2 + A_3v_3 + \cdots\cdots + A_nv_n \qquad (4\text{-}17)$$

Where; Q: total discharge, (m^3/s)

A_1, A_2, A_3.........., An: Individual cross Sectional Area (m^2),
V1, v2, v3 ...., Vn: Individual Sectional mean velocity (m/s)

(2) Method with the Spillway of A Check Dam

When the water storage is held in the upstream of the dam without sand depositting, the discharge is derived by the measurement of the depth of water overflowing from the spillway. When the cross section of the spillway is a trapezoid with 10% side grading, the discharge may be derived by the following eaution:

equation $$Q = (1.77B + 1.42h)h^{\frac{3}{2}} \qquad (4\text{-}18)$$

where: Q: discharge (m^3/s), B: length of the crown of the spillway (m), h: overflow water depth (m)

When sand is deposited up to the crown of the dam in the upstream, the discharge is derived from the product of the flow area and mean velocity measurements taken on the overflow from the spillway.

(3) Flood Level Marking Method

This is a method where the maximum discharge during floods are estimated from the flood markings. Although the method is simple to use, the result also tends to be inaccurate. The flood level is estimated by surveying the channel immediately after the flood as well as by checking the water coverage states of the vegetation in the vicinity of stream banks, surface soil washout, contamination by muddy water, and caught on trash locations, etc. Following these, the channel is cross sectionally surveyed to obtain the flow area. Additionally, the water surface slope or the streambed slope is derived from the flood stage in order to derive the mean velocity by the mean velocity formula. Then, the maximum discharge during the flood is derived by the product of the flow area and the mean velocity.

(4) Method by Rational Formula

This is a method used for determining the cross section of the dam spillway and estimating the maximum flood discharge, and discharge is derived

equation: $Q = 0.2778frA$ (4-19)

Where: Q: maximum flood discharge (m^3/s), f: coefficient of runoff
r: maximum rainfall per hour (mm/h), A: catchment area (km^2)

(5) Method by Specific discharge

The value of the discharge at a certain point on the stream or river divided by the catchment area is called the specific discharge. Therefore, the flood discharge may be approximated when the specific discharge during the flood and the catchment area are known.

The formula for the this is described below:

equation $Q = Aq$ (4-20)

Where; Q: Flood discharge (m^3/s), q: Specific discharge during the flood, the flood ($m^3/s/km^2$), A: Catchment area (km^2).

Although the Specific discharge should be derived *for* the individual points, the specific discharge for torrent streams during floods are generally as listed in Chart 4-3.

Chart 4-3 Specific discharge of torrent streams During Floods

Catchment Area (km^2)	0 ~ 10	10 ~ 20	20 ~ 40	40 ~ 60	60 ~ 80	80 ~ 100
Specific discharge ($m^3/s/km^2$)	25	20	15	12	10	8

① Coefficient of run-off: the depth of run-off is the total volume of water run-off from the watershed during a certain period divided by the area of the watershed. This figure divided by the precipitation is called *coefficient of run-off.*

Section 2 Objectives and Types of Torrent Work

1. Objectives of Torrent Work

Large volumes of gravel, soil and sand are transported downstrem during floods of torrent streams, and therefore, sedimantation zone tends to cause disasters. Therefore, torrent work has the following objectives.

1) To use as foundation of hillside works and to enhance natural restoration of the hillside landslide area, by securing the foot of hillside landslide area.

2) To prevent the erosion of streambeds and stream banks as well as to prevent hillside landslide.

3) To form sound and stable stream by preventing the washout of unstable sediment as well as stabilizing the stream by depositting the run-off sediment from the upstream devastated land and by controlling the run-off sidement to downstream.

2. Types of Torrent Work

The velocity must be reduced to decrease the erodibility of the flowing water in the torrent. The streambed gradient and the water depth must

be reduced. This is why check dams are erected. They reduce the slope of the stream bed by depositting in their backwater area.
Additionally, the streambed width increases and the water depth reduces along with the sedimentation (diagrams 4-9 and 10 refer).
Among structures erected mainly for prevention of such longitudinal erosions are sediment control dams, ground sill work ①, and small check dams ②. Since these structures are erected across the stream, they are generally called cross works.
In the other hand, when the turbulent flow in the stream becomes excessive, the water current driftes and erodes the bank, risking the danger of hillside landslide. Among the structures erected for prevention of this lateral erosion are revetment works ③ and spur dyke ④. These structures are erected on the torrent banks along the stream, and therefore are called longitudinal works.
Both cross and longitudinal work should be done in conjunction with each other in order to stabilize the torrent stream since lateral and longitudinal erosion generally take place simultaneously in torrents
Stone pitching water channel work and concrete water channel work are done at times to increase the resistance of the streambed against the erosion by the water flow. Furthermore, in the downstream of the torrent, channel work ⑤ is also done at times to protect the stream bank and to secure the streambed.

Section 3 Check Dam (Sediment Control Dam)

1. Objectives and Types of Check Dams

(1) Purpose

Check dams are structures built across the stream with the following objectives.

1) To reduce the streambed gradient to prevent longitudinal erosion. This is accomplished by erecting a tall independent dam or with low multiple stepped dams as illustrated in Diagram 4-9.

*① Explained in details later

② Small dam-like structures erected in the upstream regions of the torrent.

③, ④, and ⑤ are explained in detail later.

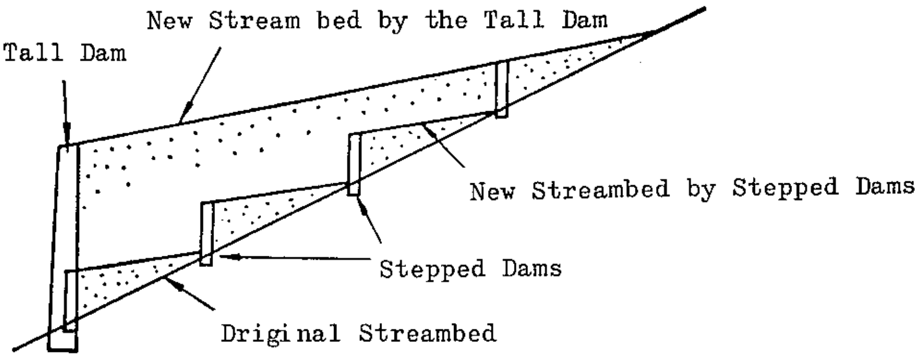


Diagram 4-9 Reduction of the Streambed Gradient

2) To prevent the hillside from collapse by securing the foot of hillside. As illustrated in Diagram 4-10, the streambed is elevated to secure the unstable foot of hillside in order to prevent the hillside from collapse as well as to preclude expanding of collapse from expanding.

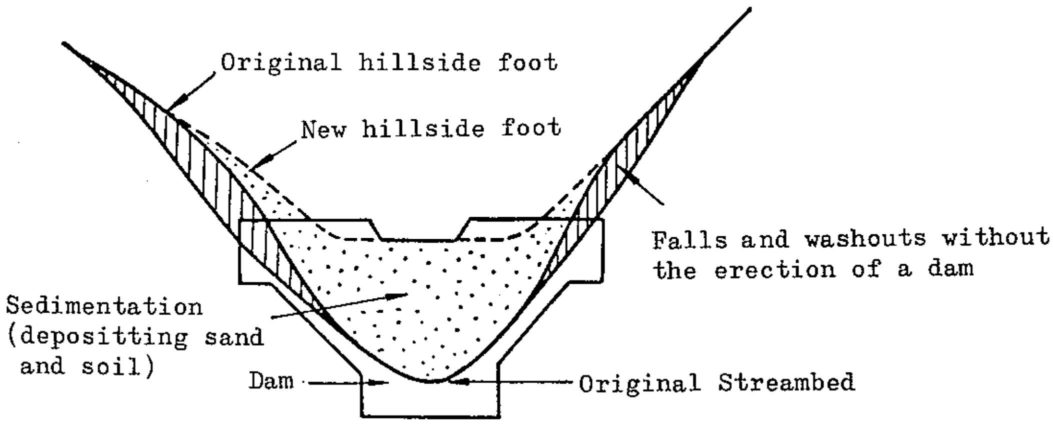


Diagram 4-10 Securing of hillside foot

3) To check the sand and gravel washed down from the upstream and controls the runoff to the downstream. Dams for such porpose are called check dams and can restrain as well as reduce the force of mud flows. The height of dams are generally constructed high as illustrated in Diagram 4-11.

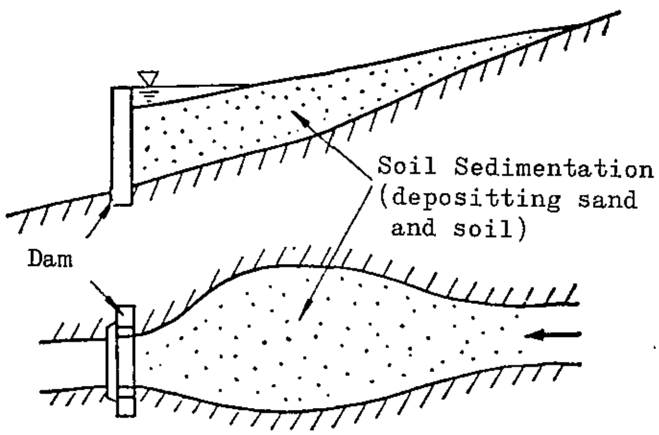


Diagram 4-11 Check of soil and sand

4) Turbulent flows are prevented and streambeds are secured in sedimentation zone. Low stepped dams are erected as illustrated in Diagram 4-12 in order to preven lateral erosion by regulating the channel.

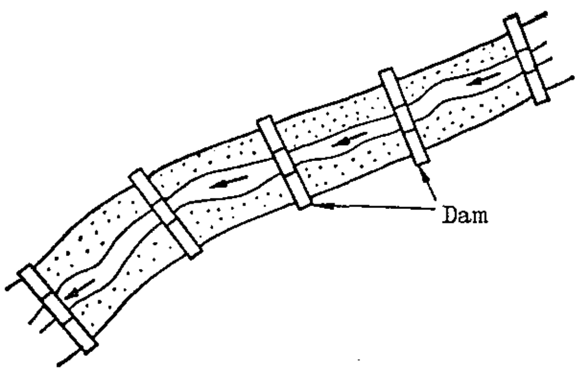


Diagram 4-12 Securing the Streambed

(2) Types

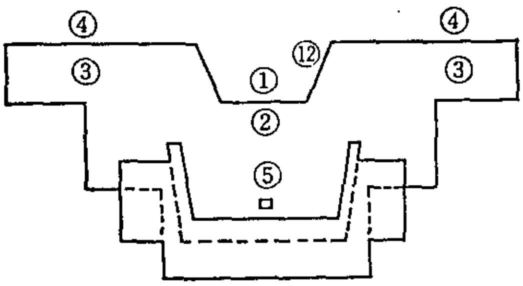
The types of check dams are generally classified in accordance with their structural material, form, and type of resistance against external force.

1) Classification in accordance with the structural material:
Wet masonry, Dry masonry, Mixed masonry, concrete, boulder concrete, reinforced concrete, concrete frame, steel, cylinder, wood and earth, etc.

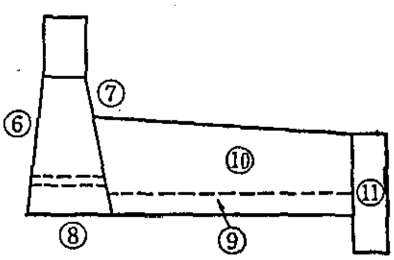
2) Classification by the form:
Straight line, arch, and buttress, etc.

3) Classification by the resistance type against external force:
Gravity and arch system, etc.

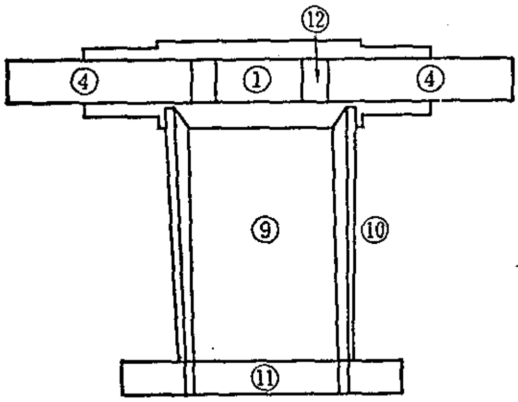
(3) Individual check Dam Section Nomenclatures



(a) Front View



(b) Side View



(c) Plane figure

① Spillway (Overflow section)
② Spillway Crown (Crown)
③ Wing
④ Wing Crown
⑤ Drainage hole
⑥ Upstream slope
⑦ Downstream slope
⑧ Base of Dam
⑨ Front Apron
⑩ Side Wall
⑪ Vertical Wall
⑫ Side of Spill Way

Diagram 4-13 Individual Check Dam Section Nomenclatures

(4) Major Check Dams & Their Features

1) Concrete Dam

This is a dam constructed by forming the shape of the dam with wood or steel forms and placing concrete within the forms. The dam body may be made into an uniformed structure with this method. Additionally, dams made with this method exhibit superb durability, and therefore, tall dams can be made. This is why this method is most widely used lately. Gravity type concrete dams are most representative of this method. This dam resists external force with its own weight and form is generally straight line and may be constructed on gravel layers or soft rockbeds upon treatment to secure the base ground.

Arch type concrete dams relate the external force to the rockbeds in the both sides with the arch effect to resist external force. The dam body may be constructed thinner than the above gravity dams with this method, but the design and construction become more complicated. Therefore, arch dams are constructed when the foundation ground as well as the both sides rockbeds are rigid and the valley is narrow compared to the height of the dam.

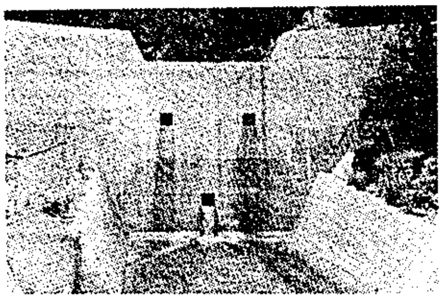


Diagram 4-14 Concrete Dam

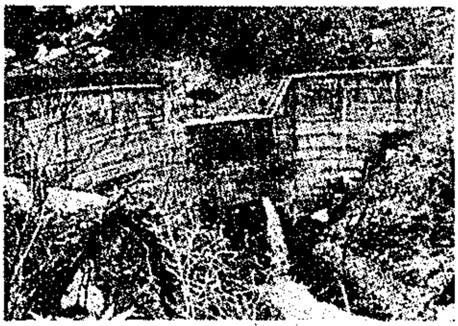


Diagram 4-15 Arch Type Concrete Dam

2) Steel Dams

The base and wings of this type of dam are constructed with concrete. In top of this base, buttress frames comprised of H framed steel assembled into inverted V shapes are placed every 2 meters. The dam body is then formed by placing L frame steel in screen form onto the front of these frames.

The material quality is uniformed since the structural members are factory produced. Additionally, this construction work requires no exclusive technology since the work is accomplished by simply assembling the materials. Therefore, the work may be performed efficiently in a short time period and may be used in undeveloped areas using existing transportation systems. Furthermore, harmless sand is sifted and run-off with the screen structure and only large gravel and boulders washed down by floods are intercepted. Therefore, the hydraulic pressure may be reduced with this large permeability. Due to these reasons, many construction examples are seen despite the short period since its development. However, this method is not suitable for high acidity water due to the corrosiveness of the steel members and securing jointbolts. Moreover, this dam is fragile against impacts as well as force from the diagonal direction. Therefore, this method cannot be done in areas prone to large scale mud flows as well as in curved flow areas.

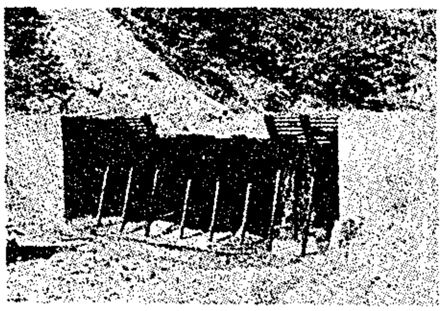


Diagram 4-16 Steel Dam

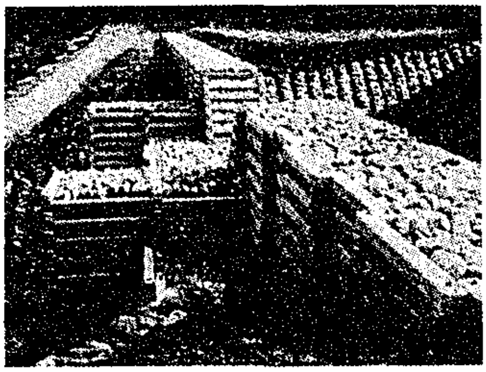


Diagram 4-17 Concrete crib dam

(3) Other Dams

Concrete crib dams are constructed on concrete foundations with square, concrete columnar blocks assembled into a well crib shaped frame filled with boulders. This has improved durability over the wood crib dam and exhibits features identical to the steel dam for construction. However, blocks in the vicinity of crown tend to become damaged in this method. This method is generally done in minor streams with minimal discharge and abundant gravel or in minor streams within the land slide area.

Check dams employing wire cylinders have been long used in bare mountain areas. This work is accomplished by piling on one or more wire cylinders and stopping them with piles. Since this method exhibits superb flexibility as well as compativility with the scour of the foundation and land subsidence, it is done in minor streams on unstable earth.

However, it should only be used for temporary structure due to corrosion of the steel wire resulting in low durability.

Dry masonry dams are constructed simply by piling stone materials and were previously employed for check dams in minor streams in undeveloped areas. Wet masonry dams are constructed of masonry coated with mortar as an adhesive and internally filled with boulders. Although this type of dam was often constructed since the tall dam could be erected by this type in areas where satisfactory stone materials were available, they have been rarely constructed in recent years.

2. Location and Direction of Check Dams

(1) *Erection Location*

The following conditions must be satisfied for the erection of a dam:

1) The dam must be erected in a spot with rigid bedrock in the streambed or stream banks. This condition must be satisfied since the dam may collapse if the discharge over-flowing the dam washes out the toe of slope or erodes both sides when the foundation ground is soft.

2) The dam must be erected in a location where the valley width are narrow and the streambed slope upstream is gentle as well as where the streambed width is broad. The length of the dam may be shortened and the costs are reduced when the valley width is narrow. Additionally, large amounts of soil, sand, gravel, and rocks may be depositted when the streambed slope upstream is gentle and when the streambed width is broad.

3) The dam must be erected in the downstream of a confluence when erecting a dam in the vicinity of confluence of stream. Dams should be erected in torrent stream when one of the streams is devastated and should be located in at a point where the confluent current becomes stabilized when both streams are devastated.

4) The point where the estimated sand depositting line intercepts the present existing streambed is the site for the upstream dam when planning dams in steps as illustrated in Diagram 4-9.
Based on these principles, the dam location is determined in accordance with the objective of the dam.
Furthermore, when the objective is to prevent streambed and bothsides banks erosion as well as hillside collapse and expansions, the dam is to be erected downstream in the vicinity of these possible devastated areas. Additionally, the dams are to be stepped when this possible devastated section is long. Moreover, the dam is to be planned downstream of the sedimentation zone when the objective is to deposit run-off sediment from upstream.

(2) *Direction of the Dam*

The water overflowing the dam generally runs-off at a right angle

direction to the dam. Therefore, when the stream is straight, the dam is to be constructed at a right angle direction to the stream.
Dams should not be located in curved flow section, however, when other sites are not available, it is to be designed at a right angle direction to the tangent of line of maximum depth during floods at the center of the overflow section. Additionally, when the present existing streambed width is narrow and the stream is bent as illustrated in Diagram 4-18(a), the new streambed after the soil sedimentation in the dam often tends to become straight line. Therefore, the direction of the dam must be determined with considerations for the estimated new line of maximum depth.
Furthermore, when planning stepped dams in curved flow areas, the dams are to be designed at a right angle direction to the line connecting the center of the overflow section of the upstream and downstream dams as illustrated in Diagram 4-18 (b).

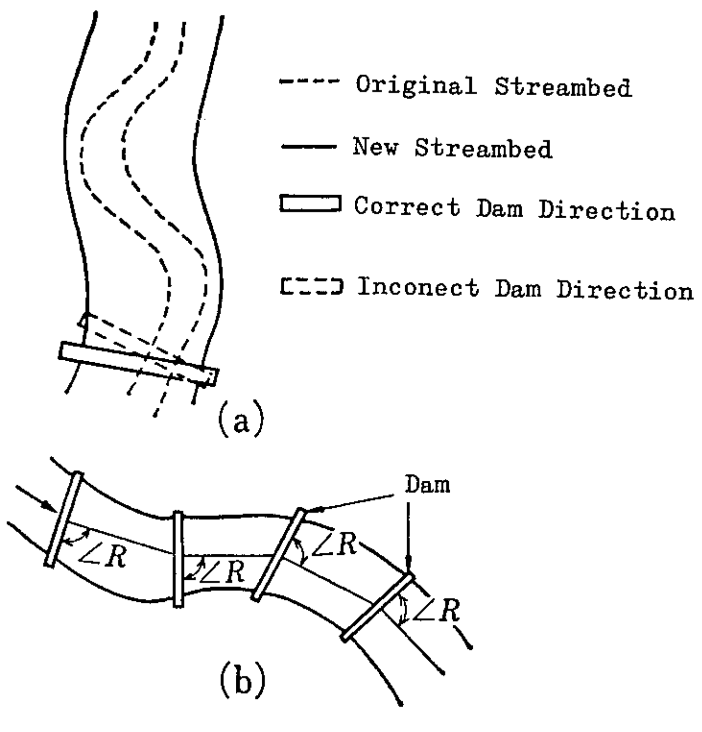


Diagram 4-18 Direction of the Dam

3. Design Accumulating Gradient and Dam Height

(1) Design Accumulating Gradient

One of the objective of check dams is to deposit soil and sand upstream area in order to make the streambed gradient gentle to produce stable stream free from a longitudinal and lateral erosion. It is important to estimate the new streambed gradient. This is called the design accumulating gradient, and the height and location of the dam is determined with this gradient figure.

The accumulating gradient of dams generally are steep when the gravel discharge from the upstream is excessive or when the gravel sizes are large, and are gentle when the discharge is large. Accumulating occurs on steep gradient during large floods, but this gradient gradually becomes relaxed with succeeding intermediate and minor floods. The gradient of the streambed is therefore changing constantly with the repetition of the this phenomena.

The design accumulating gradient for designing dams is determined with examples in the vicinity of the site as references based on the standard 1/2 - 2/3 of the present existing streambed gradient with the streambed comprising gravel sizes and the discharge, etc. taken in consideration.

(2) Dam Height

The height from the base of the dam to the crown of the overflow section is called the dam height, and the height from the streambed prior to construction to the crown of the overflow section is called the effective height. The height of the dam is determined upon considering the objective of the dam construction, ground condition, and the design accumulating gradient, etc. Therefore, the objective must be clearly distinguished as well as the foundation ground of the projected dam construction site must also be thoroughly surveyed when determining the height of the dam. The dam height in accordance with these objectives is described below.

1) Whether to construct a relatively tall dam or several low stepped dams is determined in accordance with the conditions of the project site when the objective is to prevent the erosion of hill side foot in large scale hillside land slide areas. In this case, it is

often more effective to construct several low dams in place of a single tall dam. This is because lower dams are smaller in volume and more economical as well as receive less scour on the downstream toe of slope. However, taller dams are superior to the lower versions as far as the soil sedimentation volume is concerned.

2) Low dams are constructed in steps generally when the objective is to prevent the erosion of the hill side foot of the streambank collapse area.

3) The dam height must be sufficient for the protection of the foundation when the objective is to protect the foundation of structures from scour.

4) The dam height must be as high as possible for the foundation ground and the topographical conditions when the objective is sedimentation.

(3) Sand Sedimentation Volume Calculation

Cross sectional and longitudinal sectional methods are available for derivation of the sand sedimentation volume. The longitudinal section method is explained below.

Sand depositting solid behind the dam AB as illustrated in Diagram 4-19, it is assumed that the longitudinal section becomes ABC. This longitudinal section area is multiplied by the average width of the sedimentation to derive the sedimentation volume.

Where V : sand sedimentation volume (m^3)

h : effective height of the dam (m)

$\tan \alpha$: original streambed slope

$\tan \beta$: new streambed slope

ℓ : average length of the sedimentation solid

b : average width of the sedimentation solid

equation $A'B = \ell \tan \alpha$, $AA' = \ell \tan \beta$

it becomes:

equation $AB = A'B - AA' = \ell (\tan \alpha - \tan \beta) = h$

Therefore, it becomes:

equation (5-21) $\ell = \dfrac{h}{\tan\alpha - \tan\beta}$ (4-21)

Because:

equation $\Delta ABC = \dfrac{1}{2} h \ \ell = \dfrac{1}{2} \left(\dfrac{h^2}{\tan\alpha - \tan\beta}\right)$

It becomes:

equation (5-22) $V = \dfrac{1}{2} \left(\dfrac{bh^2}{\tan\alpha - \tan\beta}\right)$ (4-22)

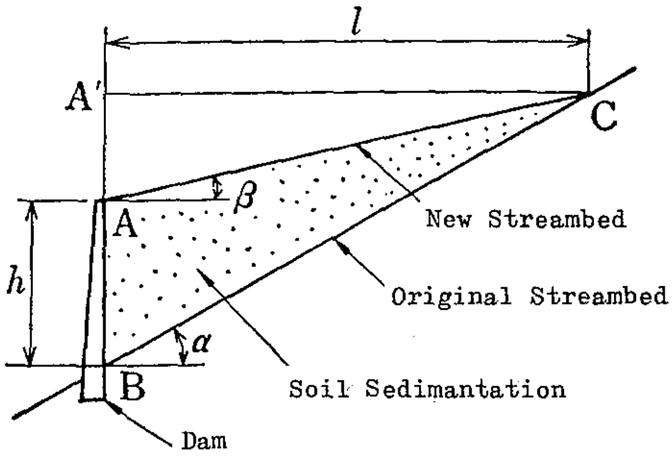


Diagram 4-19 Sedimentation Cross Sectional View

4. Spillway (Overflow Section) and Wings

I. Spillway

The part of the dam through which the overflow passes is called the spillway (overflow section) and its location, form, size, and sleeve structure is important for the preservation of dams.

(1) Location

The location of the overflow section is to be determined with the soil nature and topographical conditions of the both sides and the front apron of the projected construction site taken into consideration.

1) The overflow section may be provided anywhere when the stream banks and the streambed at the downstream toe of slope is comprised of rigid bedrock.

2) The overflow section is located in line of maximum depth when the stream bank are fragile without rigid rockbeds. (Diagram 4-20(a))

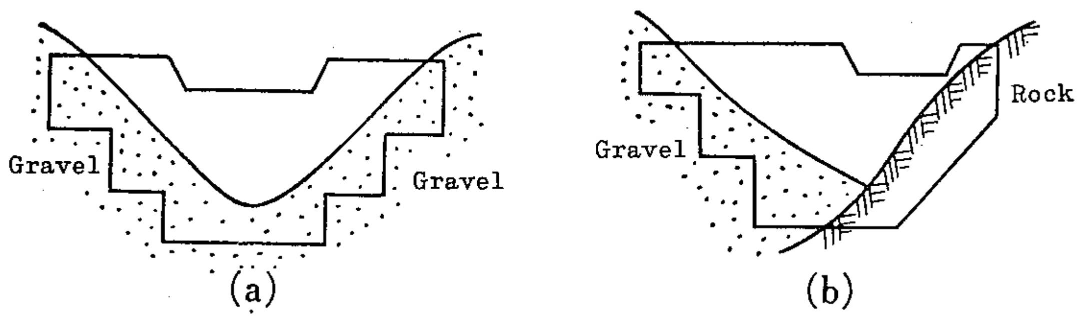
3) The overflow section is located closer to the side with the rockbed when the rigid rockbed exists only on one side. (Diagram 4-20(b))

4) The overflow section is located in a position where it will not cause erosions when structures such as revetment works, residential land, and arable land exist along the streambank downstream.

5) The overflow section is to be located in a position where are free from the effects by the water flow when collapse areas exist in the stream banks and hillsides upstream the dam. (Diagram 4-20(c))

(2) Shape

Trapezoidal, arch, and rectangular shapes are seen in overflow section. However, trapezoidal shaped overflow section are most commonly seen. The width of the overflow section should be increased as much as possible to reduce the overflow depth in order to decrease falling hydropower to minimize the washout toe of slope of the dam downstream. Furthermore, in streams with wide streambeds and large gravel discharge volumes, compound sectional shapes are employed at times as illustrated in Diagram 4-20(d) since gravel may sediment on the overflow section and increase turbulent flows.



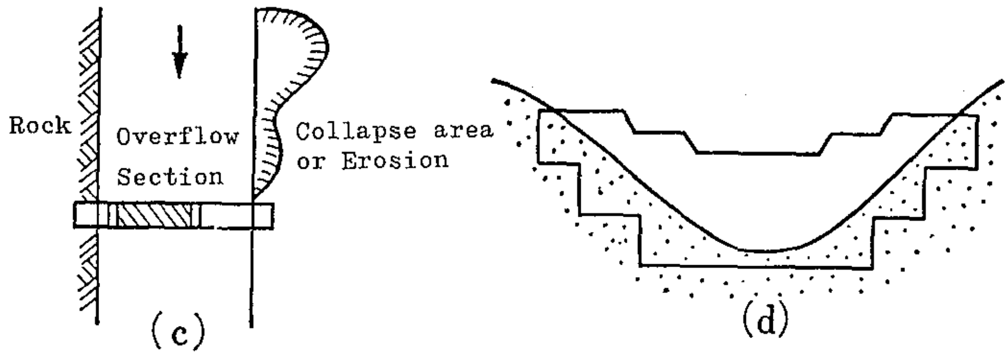


Diagram 4-20 Location and Shape of Spillways

(3) Cross Section

The dimensions of overflow section generally should be sufficient enough for running off the maximum discharge during floods safely with extra space for mud flow and driftwood taken in consideration. The maximum flood discharge is determined by the watershed area, precipitation, hillside gradient, forest conditions, and the hillside devastation conditions.

A sample method for determination of the cross section of the overflow section in case of open channel is explained as follows:

1) The maximum flood discharge Q is by Rational Formula (equation 4-19).

2) The diameter of the maximum gravel intra-streambed is selected. Generally, the average diameter of the largest sized intra-streambed gravel thought to have been washed down is applied.

3) The critical velocity vg of the maximum gravel is derived. $vg = K\sqrt{b}$ (Equation 4-14) is to be used.

4) The design accumulating gradient I is estimated. It should be about one half of the present existing streambed gradient.

5) A hypothetical overflow section is determined. The following calculations are to be performed using the values of 1) through 4).

(a) The cross section area F is derived by the following equation:

equation $$F = \frac{Q}{Vg} \qquad (4\text{-}23)$$

(b) The hydraulic radius R is derived by the following equation:

equation $$R = \frac{\alpha Vg^2 \pm \sqrt{(\alpha Vg^2)^2 + 4\ I\beta Vg^2}}{2I} \quad (4\text{-}24)$$

However, α and β are the coefficient of roughness of the Bazin's old Formula. This formula uses the Bazin's old Formula for Equation (4-15) C and consolidate the quadratic equation of R for derivation by the root formula of the quadratic equation:

equation $$\frac{1}{\alpha + \frac{\beta}{R}} RI = Vg^2 \quad \frac{R}{\alpha R + \beta} RI = Vg^2$$

$$\rightarrow IR^2 \rightarrow \alpha Vg^2 R - \beta Vg^2 = 0$$

The wetted perimeter P is derived by the following equation:

equation $$P = \frac{F}{R} \quad (4\text{-}25)$$

Based on the cross section area F, hydraulic radius R, and wetted perimeter P derived, the cross section is approximated with extra room for the field site conditions taken in consideration.

6) Determination of the Overflow Cross Section

The following values at the estimated overflow section are to be derived.

(a) The cross section area F', Wetted Perimeter P', and hydraulic radius R' are to be derived by Equation (4-6).

(b) The safety factor n of the cross section area is derived by the following equation:

equation $$n = \frac{F'}{F} \quad (4\text{-}26)$$

(c) The mean velocity v' is derived by Equations (4-11/12) and the discharge Q' is derived by Equation (4-8).

(d) The safety factor of the discharge n' is derived by the following equation:

equation $$n' = \frac{Q'}{Q} \quad (4\text{-}27)$$

(e) The estimated overflow section is adopted for use when the safety factors n and n' are about two to five.
Reestimate and recalculate for the adoption of the overflow section when the derived safety factor is insufficient.

(4) Protection of Overflow Section

The overflow section is worn by the run-off gravel and may become destroyed by the impact of boulders or by the pressure from the flowing water. Protection structures are therefore executed as required.

The following describes the various protection work methods available.

1) Stone Consolidation
Closely consolidated rigid stone is used not only in wet masonry dams but also for the overflow section crown of concrete dams.

2) *Rich Concrete Mixture*
The crown is especially constructed by using rich mix concrete.

3) Other Methods
Other methods which use steel plates, old rails, and fibre glass boards on the spillway crown are also available.

II. Wing

The overflow section is sufficiently to pass the maximum flood discharge. However, it must be solidly constructed since mudflow and driftwood may be generated more than expected and overflow the sleeve. Furthermore, the crown of the dam wing in locations described in the following is to be provided with an upward inclination towards the stream banks. (An upward gradient must be provided:)

(i) immediately below hillside landslide areas, (ii) at mudflow generated areas, (iii) at driftwood run-off areas, and (iv) at curved areas of the stream.

The inclination in these cases is generally about the same as the design accumulating gradient of the dam. The required embedment depth of the wing into the stream banks is about 1 to 2 meters for bedrock and about 2 to 3 meters for soil and sand. Additionally, the connecting member of the wing to the stream banks often is damaged, resulting in the destruction of the dam, and therefore must be reinforced by protection works.

5. Dam Sections and Conditions of Stability

(1) Determination of the Dam Section

The selection of the dam section for linear gravity dams is generally accomplished by selecting the height, crown width, downstream slope, and then the upstream slope to attain a cross section satisfying the safety requirements. The dam base is determined along with these items.

1) Height
The determination of the dam height is made based on Section 3-(2) "Dam Height" described earlier.

2) Crown Width
The crown width is determined by the run-off gravel dimensions, overflowing water depth, and the design accumulating gradient upstream. The crown width is about 1.5 meters in ordinary devastated streams, over 2 meters in locations where large boulders and excessive mudflow are expected, and about 1 meter in small streams with smaller sized gravel run-off such as SHIRASU or ash.

3) Downstream Slope
The downstream slope must be steep in order to protect the slope surface from damage by the discharge and gravel, etc. overflowing the dam fall directly on the front apron. The slope is about slope ratio of 1:0.2 generally, and about slope ratio of 1:0.3 for lower dams under 6 meter height dam.

4) Upstream Slope
The upstream slope is determined in accordance with the dam height, crown width, and downstream slope determined earlier, satisfying the stability conditions for gravity dams.

5) Dam Base Width
The dam base width may be derived by the following equation when the height, crown width, upstream and downstream slopes are determined.

$$B = b + (n + m)\, h \qquad (4\text{-}28)$$

where
- B: Dam base width
- b: Crown width (1:n)
- 1:n: Downstream slope
- 1:m: Upstream slope
- h: Dam height

(2) Stability Conditions

The gravity dam resists various external forces with the weight of the dam body. These external forces may be segregated into the components of hydraulic pressure and mud flow impact, sedimented sand pressure, and earthquake force. However, only the hydraulic pressure is often considered with the unit weight of the water estimated between 1.2 to 1.8 t/m^3. The following conditions must be satisfied in order to ensure the safety of the dam against these external forces.

1) Not fall
2) The dam body has not broken.
3) The baseground has not broken.
4) Not slideable

These conditions are considered satisfactorily for a unit length of the dam.

1) Stability Against Falling

The action line of the resultant force of external force and the dead weight of the dam body must be through the dam base to prevent the dam from falling forward by external forces. Only the hydraulic pressure is to be considered as the external force (overflowing water depth is to be disregarded). The stability check diagram method is described in the following paragraph. The cross section of the dam is taken as ABCD as illustrated in Diagram 4-22.

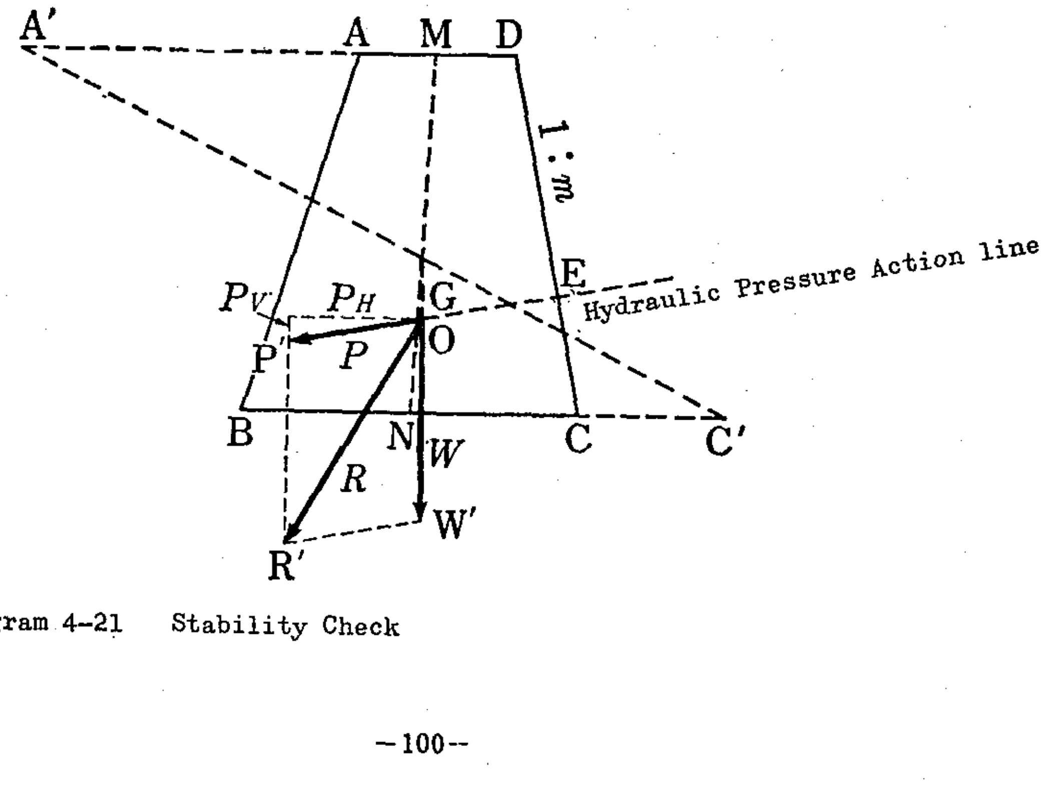


Diagram 4-21 Stability Check

With the length of the dam top AD as b, the length of the dam base BC as B, the dam height as h, the slope of the DC plane as 1:m, and the unit weight of the flowing water as γw, the overall hydraulic pressure P acting the DC plane per unit length may be derived by the following equation from the Equation (4-5).

(equation) $$P = \frac{1}{2} \gamma w\ h^2 \sqrt{1 + m^2} \qquad (4\text{-}29)$$

This overall hydraulic pressure acts the DC plane perpendicularly, and its acting point is at point E, 1/3h above the dam base.
With the unit weight of the dam body as γm, the dam dead weight per unit length becomes:

(equation) $$W = \frac{1}{2} \gamma m\ (b + B)\ h \qquad (4\text{-}30)$$

and acts in a vertical direction through the center of figure G.
Assume A' and C' are connected from the extensions of dam top AD and dam base BC so that it becomes AA' = BC and CC' = AD in order to derive the center of figure G of the trapezoidal section ABCD.
Furthermore, assume that M and N lie on the median of dam top AD and dam base BC. Therefore, the intersecting point G of the line segments A'C' and MN is the center of figure of the trapezoidal section.
Draw the acting line of the overall hydraulic pressure acting the DC plane perpendicularly through point E and the acting line of the dead weight of the dam vertically from G.
They intersect at point O in order to derive resultant force of the overall hydraulic pressure P and the dead weight of the dam W.
Establish force P line on the extension from O to EO and force W line on the extension of GO, and then draw OP' line, OW' line by certain scale size. Furthermore, by drawing a parallelogram OP'R'W' with these two sides, the length of the diagonal line OR' is the size of the resultant force R of the overall hydraulic pressure P and the dead weight of the dam W. Therefore, it is safe from falling forward when the action line of the resultant force R crosses the dam base BC.

2) Stability check of the Dam Body Against Destruction
The dam body is broken either by tensile force on the dam body or by the dam body giving way to compressive force.

In order for the dam body to be free from tensile force, the resultant force of the dead weight and the hydraulic pressure must be through the portion between middle two points in which trisect the dam base. This trisecting point is called the core point and the portion between the middle two points is called middle third. Now, assuming that the perpendicular force V acts point F which is distance a away from B on the dam base BC as illustrated in Diagram 4-23, the compressive force distribution on the dam base here becomes the maximum compressive force P_B at point B and minimum compressive force P_C at point C. The compressive force varies linearly between these BC points. P_B and P_C are described by the following equations:

(equation)

$$\left.\begin{aligned} P_B &= \frac{2V}{B}\left(2 - \frac{3a}{B}\right) \\ P_C &= \frac{2V}{B}\left(\frac{3a}{B} - 1\right) \end{aligned}\right\} \qquad (4\text{-}31)$$

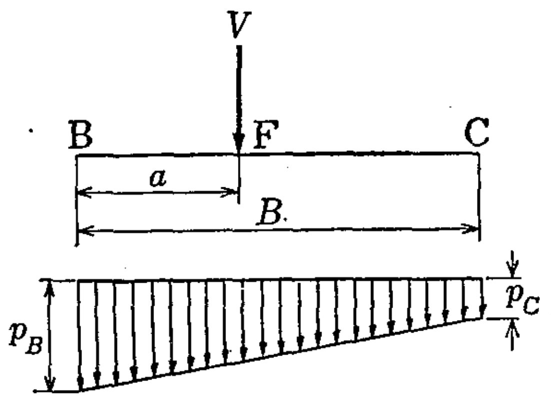


Diagram 4-23 Pressure Distribution on the Dam Base

In order for the tensile force to ineffective, $P_B > 0$ and $P_C > 0$. By analyzing this $2/3B > a > 1/3B$ appears, and therefore, it is proved that it is satisfactory when the perpendicular force V is through the middle third of the dam base.

In order for the dam body to be safe from destruction by compressive force, the allowable compressive strength K of the dam material must be greater than the maximum compressive force P_B on the dam body. Therefore, it is satisfied by the following equation:

equation $$K > \frac{2V}{B}\left(2 - \frac{3a}{B}\right) \qquad (4\text{-}32)$$

Allowable compressive strength of concrete is listed in Chart 4-4.

Chart 4-4 Allowable Compressive Strength of Concrete

Allowable Stress Variations	Allowable Strength		Summary
	t/m^2	kg/cm^2	
Allowable Compussive Strength	550	55	Age 28 days 1/4 of Compressive Strength
Allowable Bending Tensile Strength	30	3	Age 28 days 1/7 of Tensile Strength
Allowable Bearing Stress	600	60	Age 28 days 3/10 of Compressive Strength

3) Stability Check for Base Ground Destruction

It is satisfactory when the allowable bearing power of the base ground is greater than the maximum compressive force acting on the base ground. Land subsidence and destruction occur when the base ground allowable bearing power is insufficient. Additionally, since the maximum compressive force on the dam base acts the base ground directly, K may be substituted in Equation (4-32) as the allowable bearing power of the base ground.

4) Stability Check Against Sliding

The force acting to slide the dam body is the horizontal component P_H of the external force P. The force resisting the aforementioned is the reacting force by friction generated between the dam base and the base ground. The magnitude of the reacting force by friction may be derived by multiplying resultant force of the dead weight of the dam body W and the perpendicular component P_V of the external force by the coefficient of friction f of the friction between the dam body and the base ground. Therefore, the reacting force by friction must be greater than the force acting to slide the dam body in order to maintain the safe conditions. The following describes the this as an equation.

(equation) $f\ (P_V + W) > P_H$

$$f > \frac{P_H}{P_V + W} \qquad (4\text{-}33)$$

It may also be derived from the diagram since $P_V = \frac{m}{\sqrt{1 + m^2}} P$ and $P_H = \frac{1}{\sqrt{1 + m^2}} P$ on Diagram 4-22. Additionally, Chart 4-6 lists the coefficient of friction between the dam body and the base ground.

Chart 4-5 . Lists the allowable Bearing Power of the Individual Types of Base Ground

Type of Base Ground	Bearing Power t/m^2	Type of Base Ground	Bearing Power t/m^2
Hard Rock	200~300	Normal Soil	3~10
Granite (Single Horizontal Bed Thicker Than 3m)	350~1000	Clay	5~20
Porphyrite (Single Horizontal Bed Thicker Than 3m)	300~350	Ballast Mixed Clay	5~30
Graywacke (Single Horizontal Bed Thicker Than 3m)	150~600	Ballast	30~60
Lime Stone (Single Horizontal Bed Thicker Than 3m)	160~240	Sand Mixed Ballast	20~50
Soft Rocks (Tuff, Sandstone, Shale)	70~150	Normal Sand	10~40
Sedimentary Rocks (Low Concretion)	50~60	Hard Clay	20~50
Conglomerate Gravel (High Concretion)	70~80	Wet Clay	15~20
Sand (High Concretion)	70~80	Mud	0
Sandy Clay	15~20		

Chart 4-6 Coefficient of Friction of the Individual Materials

Type of Material	Coefficient of Friction
Between Masonry and Masonry	0.6 ~ 0.7
Between Good Quality Stone and Masonry	0.6 ~ 0.7
Between Ballast and Masonry	0.5
Between Sand and Masonry	0.4
Between Dry Clay and Masonry	0.5
Between Wet Clay and Masonry	0.3

6. Drainage Hole

(1) Objective

The purpose of drainage hole is to shift the drainage and flowing during the construction of the dam and to reduce the hydraulic pressure on the dam body as well as upon the seepage pressure by sand sedimentation after completion.

(2) Location, Quantity and Dimensions of Drainage Hole

The location and quantity of drainage holes vary in accordance with the purpose of the drainage hole and the dam planning.
A single drainage hole above the streambed line is sufficient for dam construction on narrow streambeds. Several drainage holes must be provided when the streambed is wide since the main water stream shifts with every flood.
Several small drainage holes must be provided when the objective is to minimize the hydraulic and seepage pressure. In such a case, drainage holes of the bottom row are to be provided on the streambed line with the higher holes arranged in reeling form. The drainage holes here must be provided with adequate clearance with the neighboring hole and must be not perpendicular line. Additionally, drainage holes in the top row must be located 1.5 to 2.0 meters below the overflow section crown since they may become the cause of the dam destruction by the impact of the mud flow.

The drainage hole of the dam down stream is to be designed below the base ground of the dam upstream when constructing stepped dams. The dimensions of the drainage hole are to be sufficient enough for running off several floods for a year, since it becomes the weakest point of the dam body when the dimensions are excessive. Generally, drainage holes are square or rectangular with 0.2 to 0.4 meter sides but are also substituted with circular versions with similar sectional areas. Square or rectangular drainage holes with 0.5 to 1.0 meter sides are provided for tall dams executed for sand sedimentation.

7. Protecting from Scouring

It is desirable for the dam base ground to be comprised of solid bedrock. However, dams often must be constructed on gravel layers due to the objective of the dam. In such a case, the front apron is scoured by the flowing water and gravel overflowing the dam. It become a cause for the destruction of the dam when left in such condition for extended periods of time since the base ground also becomes scoured. Therefore, front apron work, counter dams, and riprap work are performed to prevent the scour. The selection of the these works must be made in accordance with the composition of the gravel in the streambed, discharge, and the dam height.

(1) Front Apron Work

This work is used to prevent the scour by securing the front apron with concrete in direct connection with the downstream part of the dam. This work is used in the downstream part of the stream when the diameters of the run-off gravel and streambed gravel are small with large discharge.

1) Length

Front apron works are executed in the part where the discharge overflowed dam and gravel fall. Therefore, the distance from the toe of downstream slope to the dam foundation level where the flowing water overflowing the dam overflow section down is derived by the following equation and is extended marginally in order to logically derive the length of the front apron.
(Diagram 4-25 refers. The front apron work height is to be at a level identical to the counter dam crown).

equation $$\ell = V\sqrt{\frac{2\,(h+t)}{g}} - nh \qquad (4\text{-}34)$$

where ℓ : The length of the front apron from the toe of downstream slope (m)

h : The effective fall of the dam ① (m)

V : The surface velocity of the flowing water leaving the dam (m/s)

t : Overflow water depth (m)

g : Acceleration of gravity (9.8 m/S^2)

(1:n): Down stream slope

The length of the front apron is executed by experience as the following.
Incase of low dam, it is 2 times total length of overflow water depth and the effective fall of the dam.
In case of tall dam, it is 1.5 times total length of overflow water depth and the effective fall of the dam.

2) Thickness
The thickness of the front apron work has not yet been logically and actually analyzed. It is generally executed with a thickness of 0.5 to 1.0 meter by experience.

Front Apron Work is Generally Concrete Structured
Additionally, wire cylinders and wooden mattress are also used where the discharge is minimal and only when soil and sand are runoff. However, these lack durability and are only considered as temporary measures. Additionally, the gradient of the front apron is generally level, but is also sloped in accordance with streambed slope when the streambed slope is excessive.

4) Vertical and Side Walls
A vertical wall is provided at the tip of the front apron for depth of embedment since the downstream tip of the front apron on gravel layers becomes scoured.
The soft ground in the sides of the front apron becomes eroded

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① The height from the front apron tc the overflow section crown.

② Frame constructed with logs and filled with boulders for sinking into the streambed.

since the flowing water falling from the dam generates turbulent flows on the front apron. Therefore, side walls are provided to protect the both sides. The height of the side walls must be determined so that the channel section of the front apron becomes larger than the overflow section of main dan. Additionally, the crown of the side wall must be provided with an upward gradient toward the upstream. The bottom part of the part connecting the side wall to the main dam must be far 0.5 to 1.0 meter from the shoulder line of the dam overflow section. This is done to prevent the side wall from destruction by the flowing water and gravel overflowing the overflow section of main dam.

(2) Counter Dam Work (Secondary Weir)

Low dams provided in the downstream of the dam to prevent the front apron from becoming scoured are called counter dams and the protected dam is called the main dam.
A water cushion is provided between these dams to minimize the impact of the falling water flow and gravel in order to prevent scouring.
This work is executed in the upstream of torrents when the streambed is packed closely with boulders or when the diameter of the run-off gravel is large.

1) The Overlap Height of the Main and Counter Dams
The main and counter dam heights must be over lapped. To increase unnecessarily this overlapping height is not only uneconomical because of the increased height of the counter dam but also causes increased scour in the downstream of the counter dam. The overlap height generally must be about 1/3 to 1/4 the height of the main dam. (Diagram 4-25)

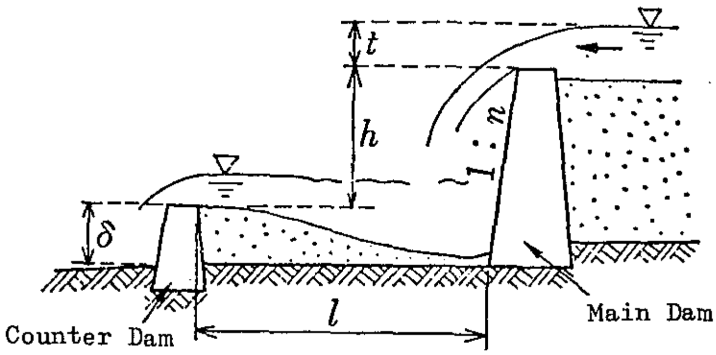

Diagram 4-25 Main and Counter Dams

2) The Interval between the Main and Counter Dams

The interval is determined in accordance with the calculated length of the apron.

(3) Joint Execution of the Front Apron and the Counter Dam

The front apron work and counter dam work are executed together when constructing a fairly tall dam in a stream with a large discharge and large sized gravel runoff. This is done in order to protect the front apron from abrasion and destruction by the boulders overflowing and falling from the main dam by the water cushion of the counter dam.

(4) Riprap Work

This is construction where concrete blocks and large boulders are dropped into the scouring part of the front apron in lieu of front apron works and counter dams to secure the these scouring part. However, the dropped materials often become washed away and therefore, this method should only be considered as a temporary measure.

8. Volume Calculations of Parts of a Dam

(1) Form and Cubic Volume Calculation

Calculations are made in the following order:

1) Draw the front view and plane figure of the dam with side views drawn at the sides and segregate the dam with horizontal lines intersecting the points where the shape of the dam changes on the front view and side view.

2) Derive the top length ℓ, bottom length L, and the height h of each section on the front view. Additionally, derive the top width b and the bottom width B of each section on the side view.

3) Derive the form area A of each section with the following equation:

(equation) $$A = \frac{\ell + L}{2} h \qquad (4\text{-}35)$$

When these are summed, it becomes the area of the surface of the dam when the dam slope is perpendicular. Additionally, the area when the slope ratio is 1:n is derived by multiplying $\sqrt{1+n^2}$ by the area in the perpendicular case. This area must be derived for both the up and downstream. Moreover, the areas of the form for the overflow section side and the drainage hole must be derived. The total sum of the aforementioned is the area necessary for the form of dam c onstruction.

4) The individual dam section cubic volumes generally derived by the following equation:

(equation) $$V = \frac{h}{6}\left\{ 2\ (\ell b + LB) + \ell B + Lb \right\} \qquad (4\text{-}36)$$

However, when the shape of the segregated section is rectangule in either one of the front or side view, the cubic volume is derived by the following equation:

(equation) $$V = A\,\frac{B + b}{2} \qquad (4\text{-}37)$$

Additionally, when the shape of the regregated section is rectangule in both diagrams, the cubic volume is derived by the following equation:

(equation) $$V = AB \qquad (4\text{-}38)$$

The cubic volume of the dam is the total of the above volumes minus the drainage hole volume.

(2) Base Excavation Volume Calculation

Calculations are made in the following order:

1) Draw the front view of the designed dam into the cross sectional diagram of the stream at the center line of the dam overflow section crown. Additionally, draw a side view at the side.

2) Segregate the front view with perpendicular lines. These lines are to be drawn where the shape of the dam base and the ground surface gradient change.

3) The following values must derived for the individual blocks on the front view.

   a) Height h': The height from the dam base to the ground surface at the center of each block.

   b) Extension ℓ : The length of each block.

4) The following values are to be derived on the side view in the center of each block.

   a) Add extra excavation space of the both sides to the dam base width for bottom width B'.

b) The top width b' may be derived by the following equation assuming that the slope of the base excavation is 1:n.

(equation) $$b' = B' + 2nh' \quad (4\text{-}39)$$

5) Derive the sectional area of each block by the following equation:

(equation) $$A' = \frac{B' + b'}{2} h' \quad (4\text{-}40)$$

6) Derive the base excavation volume V' of the individual blocks by the following equation to sum them to derive the total base excavation volume of the dam.

(equation) $$V' = A' \ell' \quad (4\text{-}41)$$

9. Dam Construction

Lately, concrete dams are most widely constructed. The following explains the basic execution methods:

Construction Survey

The most important item for the construction of a dam is to expedite how efficiently, economically, and safely the work can be executed in the limited construction period. Therefore, it is highly important to establish an effective project schedule based on the survey data. The following listed surveys should be completed prior to designing the dam. However, further detailed surveys are necessary when constructing relatively large scale dams.

1) Topographic Survey

1/100 to 1/200 scale cross sectional diagram at the center of the dam is already completed at the design stage of the dam. Therefore, detailed surveys of the area in the vicinity of the projected dam construction site must be performed prior to the execution of the work. Exposed bedrock, spur line, flowing water level position, and large boulders, etc. are then inscribed onto the 1/500 to 1/1000 scale topographical chart of the projected dam construction site. Additionally, the temporary diversion channel, soil dumping area, and material storage area are to be indicated on the 1/500 to 1/1000 scale topographic chart of the surrounding area.

2) Geological Survey

Detailed surveys are required when constructing tall or arch type dams. Not only the bearing capacity of a gravel layer or the type of rock in bedrock is required to be identified but faults and fractured zones must also be thoroughly surveyed.

3) Weather and Flow Règime Survey

Throughly survey the weather and flow regime since they effect the work period most critically. Flood conditions and low water periods in particular are to be surveyed over with data for long periods of time. These data are highly beneficial for determining the execution period as well as designing the temporary coffer dam and temporary diversion channel.

4) Material Transportation Facility Survey

Most of the dam construction sites are located in areas where transportation is difficult. Therefore, the quality of the material transportation facility greatly effects the execution of the work. The best transportation facility is a road. Survey the width, gradient, curvature, and bridges as well as necessary improvements and repairs when an existing road exists.

Temporary Coffer Dam and Temporary Diversion Channel

The stream or river is blocked and is drained through the temporary diversion channel during the execution of the work in order to facilitate the work to attain certain dam execution results.
The best blocking and temporary diversion channel methods are selected in accordance with general judgement of the discharge, the topography, soil nature, thickness of the streambed sedimentation of the projected execution site, and the dimension of the dam. It is satisfactory with soil bag blockade in streams with minimal discharge. However, rigid soil and stone blockade, sheet pile blockade, and concrete blockade are employed in streams with large discharge.

Diagram 4-26 Temporary Diversion Channel

The overall stream current is blocked in the up and downstream of the execution site and the water is drained with steel or wooden conduits or by a pump when discharge is minimal in a narrow width stream. Additionally, half of the stream is blocked at a time to execute the work when the discharge and the width of the stream is large. Furthermore, drainage tunnels are provided at times when the streambed width is narrow in contrast to the discharge and the dimension of the dam is large as well as the base excavation is deep.
The flow capacity volume of the temporary diversion channel is to be large enough to run off the flood discharge during the execution period based on the execution survey data.

(3) Base Excavation

The streambed is excavated down to expose the bedrock or the gravel layer is excavated to an adequate depth to secure the bed for the base when constructing the dam. This work is called the base excavation.

1) Gravel Base Excavation

The unfixed soil layer is removed and to excavate the thick gravel layer for 2 to 3 meters depth when the streambed is comprised of a gravel layer. The base excavation width is to be dug with 0.2 to 0.4m extra space than the dam base width for the execution of the form. Additionally, the base excavation gradient is to be safe enough against falling by rainfall and river bed water. The base excavation slope ratio is to be between 1:0.4 to 1:0.8 in case of soil. Mechanical excavation is recently more employed although manual excavation is also possible. However, unnecessary excavation volume often occurs when the entire excavation is accomplished by machinery.
Furthermore, re-excavation occurs in the streambed when it is left unattended for a prolonged period of time after the excavation. Therefore, the base excavation work is to be executed in combination with the concrete placing work schedule.

2) Bedrock Excavation

Explosives are generally used to excavate bedrock. It is important at this point to pay close attention to prevent from loosening the bedrock in the vicinity of the dam foundation at this point.

Therefore, the bedrock is to be excavated manually or with a rock drill instead of explosives upon excavating down to the designed foundation height. The base excavation depth is to be determined in accordance with the structural quality of the bedrock and weathering conditions as well as the existence of faults and fractured zones. The depth generally is between 1.0 to 1.5 meter. The bedrock excavation slope is to be perpendicular or about ratio of 1:0.1. Supplementary excavation is not performed at times in case of a hard bedrock. Moreover, safety should be thoroughly maintained when employing explosives.

3) Residual Soil

The residual soil is to be primarily transported to the upstream of the dam wing with consideration given to preclude this soil from becoming washed out during floods.

(4) Base Ground

1) Gravel Base Ground

The bottom is to be covered and packed with boulders, ballast and gravel prior to the dam construction when the dam supporting foundation is comprised of gravel.

2) Bedrock Base Ground

The bedrock surface is to be thoroughly cleaned with wire brush to make it rough, and is to be washed with water. Approximately 2 cm thick mortar is to be applied on this surface in order to erect the dam above this foundation.

3) Base Ground Treatment

Ground improvement treatment is to be applied in order to prevent ground subsidence and devastation when the base ground is fragile and soft. Piles are to be driven as pile foundation in case of a gravel foundation.

Additionally, the grouting method where mortar, etc. are injected by pressure is used in case of a bedrock.

(5) Construction

1) Required Concrete Characteristics

The following characteristics are required for the concrete used *for dam construction:*

(a) Compressive Strength and Water Cement Ratio

The compressive strength required for concrete dams is generally said to be about 10 kg/cm^2. The necessary water cement ratio derived from this compressive strength is considerably greater than that based on durability of concrete. Therefore, the water/cement ratio is generally derived from durability of concrete.

(b) Durability and Watertightness

Durability is highly important for dams constructed in violent climatic variation areas due to the excessive surface weathering and erosion generations. The watertightness and durability are generally improved with greater unit cement volume and lower unit water volume. Air entraining agent is used for improving the durability and watertightness with approximately 3% air volume expected to be adequate.

(c) Abrasion and Impact Resistance

The spillway crown, downstream slope, and front apron, etc. which receive abrasion and impact are applied with rich mixture concrete, special concrete mixture, or special treatment at times.

2) Mix Design

Ready mixed concrete is often used lately. In such case, the mix design conditions are to be specified when ordering upon selecting the ready mixed concrete factory. It is normal then for the concrete manufacturers to design the concrete mix proportion in accordance with the specified conditions. The following are the conditions of the mix design:

(a) Cement Classification

Normal Portland Cement, Moderate Heat Portland Cement, Portland Blast Furnace Slag Cement, etc.

(b) Maximum Size of Aggregate

Larger maximum size aggregate is better in the case of a well-graded aggregate. It is generally said that maximum size 150 mm aggregate is most suitable for the dam concrete. However, 40 to 80 mm is the limit for ready mixed concrete.

(c) Slump

Excessive bleeding occurs when large slump concrete is used although the workability may be facilitated. Therefore, minimum slump concrete with the workability still maintained is employed. It generally is about 5 cm at the concrete placing site.

(d) Specified Concrete Strength

It is said that the maximum compressive strength of a gravity type dam with a height of 15 meters is about 10 kg/cm^2 and about 40 to 55 kg/cm^2 for an arch type dam. The specified concrete strength therefore is the compressive strength determined in accordance with the dam height and the stream condition added with the relative safety factors.

(e) Water Cement Ratio

The water cement ratio must be altered in accordance with the dam construction location and the weather condition, etc. It generally is about 58 to 62%.

3) Concrete Placing

Wooden forms must be thoroughly wetted with water and steel forms must be coated with oil prior to the placement of concrete as preparation work. Additionally, the part where the concrete is to be placed must be spread with mortar.

One hour may have passed at times from the mixing when employing ready mixed concrete for placement. In such case, close attention must be paid to prevent the material from separating since the slump and air volume become reduced during transportation.

Cable buckets and portable vertical chutes are employed for placing the concrete. Although the slanting shute is frequently employed due to its ease of employment. However, it should only be employed when other methods are unemployable since the material tends to become separated with this method. In such case, the concrete should not be dropped freely from heights in excess of 1.5 meters.

Diagram 4-27 Concrete Placing

Additionally, the concrete should be placed in the placement site only and should be avoided from movements of concrete. A layer of concrete placement should be about 30 to 50 cm in order to be able to be compacted as necessary, and the daily lift height should be between 0.75 to 2.0 meters.

The joint where the concrete is joined by the placement of fresh concrete over the solid concrete is called the horizontal placement joint. These horizontal placement joints should be avoided from being placed in points acted by excessive force as well as rear the water level where excessive weathering occurs since it tends to become the weakpoint of the concrete structures. The necessary concrete age for placing additional concrete is at least three days for lift heights under 1 m and five days for lift heights between 1.5 to 2.0 meters.

The concrete surface should be scrubbed with wire brush within 24 hours from hardening while applying water in order to thoroughly remove foreign objects and to make the surface roughness. The concrete is then placed after laying mortar on this prepared surface.

Crackes may become generated in large concrete structures by the expansion and contraction occuring during the hardening or the following temperature changing period or by the differential settlement of base ground. Flexible joints are therefore provided in order to preclude this crack generation. It is safer to provide these expansion joints every 15 meters for gravity dams with dam body lengths in excess of 30 meters.

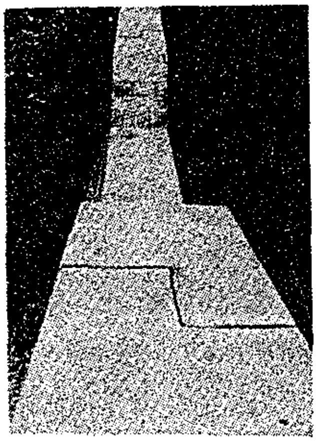

Diagram 4-28 Flexible Joints

The width of the joints are to be between 1 to 3 centimeters and is to be filled with joint materials such as asphalt.

4) Compaction

The concrete is to be compacted immediately after placing. When compacting with concrete vibrators, they are to be perpendicularly inserted with less than 60 cm interval. The concrete becomes free of cubic volume reduction when the compacting is sufficient, and water appears on the mortar surface as well as the concrete exhibits a uniformed blend appearance.

5) Curing

Although it is felt as though the work is completed when the concrete placement is finished. However, curing after the placement is also highly important since the quality of the curing during the solidifying process greatly effects the characteristics of the solidified concrete.

The adequate curing temperature is between 10 to 20° centigrade. Negative effects occur to the long term concrete strength and the strength may become reduced when cured at temperatures in excess of 35° centigrade. Additionally, concrete becomes safe against breezing once a strength of about 35 kg/cm^2 is attained although the concrete freezes at about -3° Celsius.

The concrete does not harden and the strength remains low as well as the durability and the water tightness become negatively effected when the concrete surface dries. Rice straw mats, etc. are therefore applied as well as water is sprinkled to maintain the surface damp in order to prevent the concrete surface from desiccating. Water sprinkling in this case should be accomplished from above the rice straw mats. The wooden forms should also be thoroughly sprinkled at this point. Moreover, water should be sprinkled as well as straw mats should be applied as deemed appropriate even after the form is removed. The curing time for normal Portland Cement and Moderate Heat Portland Cement is about 14 days and about 21 days for Portland Blast Furnace Slag Cement or when flyash cement is employed.

6) Gap-filling (MAZUME)

This is an important work to fill the gaps generated during the excavation of the base ground and the both sides stream banks. Both the base ground and the parts of wing embedment to stream banks are filled with concrete in case of a rockbed base ground. The base ground is filled with boulders and the parts of wing embedment to stream banks are filled along the original ground line with wet masonry retaining walls in case of gravel.

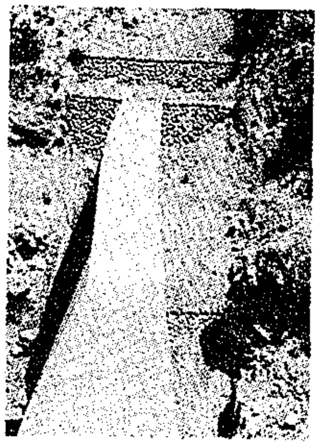

Diagram 4-29 Gap Filling

Section 4 Groundsel Sill Work

1. Objective

Since gravel discharge from the upstream is few, the streambed may become lowered or the foundations of retaining walls or other structures may become washed out in the downstream regions of streams where the upstream region is stable or where the restoration of devastation is progressed. Therefore, structures constructed across the stream to maintain the existing streambed from lowering as well as to prevent turbulent flows and to secure the streambed in the siltdeposit regions are called ground sill works.

2. Cross Section

The ground sill work is structurally almost identical to a soil conservation dam. Therefore, the ground sill work cross section is determined in accordance with the dam section calculation. The height generally is 2 to 3 meters, and is not to be excessively protruded on the streambed. The crown width is to be about 1.0 to 1.5 meters. Additionally, the upstream gradient is to be perpendicular and the downstream sloped is to be about ratio of 1:0.2.

3. Spillway and Sleeve

The position, shape, and section of the spillway are determined in accordance with those of the dam. The sleeves are to be thoroughly inserted into the banks in accordance with the hardness of the ground, the strength of the retaining wall and the topography since the ground sill work is often executed in the downstream regions of the stream.

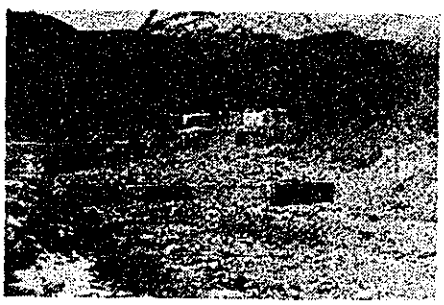

Diagram 4-30 Ground Sill Work

4. Foundation

The rooting of the ground sill work foundation is to be more than 1.0 meter when the streambed is comprised of a gravel layer, and about 1.0 meter when a rockbed or large boulders exist.

5. Wash-out Prevention

Aprons are to be provided when the streambed to be applied with bed sill work is comprised of a gravel layer. The length of the apron is to be two to three times the length of the head between the overflow and the apron surface. Additionally, the thickness of the apron is to be about 0.7 to 1.0 meter. Furthermore, the downstream edge is to be provided with a vertical wall as well as side walls are to be provided on the banks of the apron when rockbeds are not exposed.

6. Clearance

The streambed length that can be secured with a single bed sill work is short since the bed sill work is generally low. Therefore, bed sill works are often designed in steps. In such case, the clearance is to be designed appropriately in combination with the height and the designed streambed gradient. When assuming the height of the bed sill work to be constant, the clearance may be derived by substituting the of equation (4-21) as the distance.

Section 5 Revetment, Spur dyke and Channel Works

1. Revetment

(1) Objective

Not only is the streambed but also the banks are eroded in streams. Therefore, structures constructed along the stream on the banks in order to prevent the banks from side erosion are called retaining walls. Retaining walls are constructed in the concave sections of the banks where the discharge impact, land-creep hillsides or possible land-creep hillsides, and the fragile sections of the banks where the dam sleeves are inserted. Additionally, retaining walls constructed in the downstream are executed in combination with the ground sill work and spurdyke as the main body of the channel work in order to prevent the banks from devastation.

(2) Variations

Retaining walls may be classified into concrete, concrete block, concrete frame, stone filled concrete, wet masonry, stone consolidation, cylinder, and wicker depending on the structural material employed. Concrete, concrete block, and wet masonry retaining walls among the aforementioned are most commonly executed. Additionally, cylinder and wicker retaining walls are executed at times in smaller streams with minimal gravel discharge.

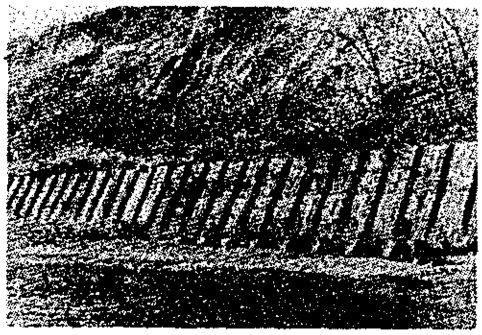

Diagram 4-31 Concrete Revetment works

Concrete retaining walls are executed in areas where the soil on the hillside may move and where ample safety is required due to the excessive dorsal pressure. The slope gradient is generally sufficient ratio of 1:0.3 to 1:0.5. Furthermore, although the thickness is determined in accordance with the soil pressure, slope gradient, and height, the average height is generally to be between 0.3 to 0.5 meter with the foundation broad and the crown narrow. Moreover, back filling gravel and weeping are necessary in order to minimize the dorsal water and soil pressure.

(3) Gradient Line

Curvatures are to be slow as much as the topography allows when determining the gradient ① line of reventment. Additionally, the

① The line of front slope

gradient line is to be isolated away from the land creeping hillfoot to provide sedimentation areas for the fallen earth when soil falling from the hillside is expected after the execution of revetment. Both ends in the up and down stream of the revetments are to be well werapped into the banks to preclude the discharge entry to the rear from the edges.

(4) Height

The height of the revetment crown is to be 0.5 to 1.0 meter above the designed water level [1] so that the crown does not become overflown by the discharge during floods. The height in the convex parts of curved flow areas are to be sufficiently high for safety since the water level elevates considerably higher than the facing bank. When designing revetment in the upstream of dams and ground sill wirks, they are to be erected in the some or higher heights as the crown of the wing of these structures. Additionally, the upstream parts are to be raised along the designed streambed gradient.

(5) Foundation

The flow velocity increases in the vicinity of the revetment, causing the foundation to become eroded when revetment are constructed. Therefore, the revetment foundations are buried at least one meter deeper than the designated streambed height. The foundation of the revetment at the upstream junction to the side work is to be about one meter below the overflow section crown and have the same height as the sidework foundation in the downstream, and it is to be retreated from immediately below the overflow section shoulder according to the side wall.
Additionally, foundation procedures such as pile driving, base logs, and stepped foundation, etc. are used when the foundation is soft.

(6) Scour Prevention

Rooting as well as hardening work are executed in areas in which revetment foundations are prone to become scoured by the discharge. Side works are most desirable for root hardening construction,

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① The designed water level is water level to be able to runoff with safety designed high water discharge in the stable river bed. Maximum flood discharge in the past is employed as the designed high water discharge.

however, rubble, wood work mattress, and various concrete blocks are used for partial scour prevention as well as for scour prevention in gentle streambed gradient areas.

2. Spur dyke (Grain works)

(1) Objective

Spur dykes are structures protruding towards the center of the flow from the banks and are constructed along with revetments, etc. Objectives of this work are to:

1 Isolate the current from the banks to prevent erosion of the banks.

2 Reduce the flow velocity in order to sediment soil.

3 Restrict the channel width to suppress turbulent flows and drifts to prevent side erosion.

This work is generally done in places with wide streambeds and gentle streambed gradient.

(2) Variations

Spur dykes are segregated into perpendicular, upward, and downward spur dyke depending on their direction of protrusion towards the center of the flow as illustrated in Diagram 4-32. These three types each posses exclusive features. Soil Sedimentation occurs between the spur dyke, and the scour of the head is minimal with perpendicular spur dyke. Soil sedimentation along the banks and the spur dyke as well as the scour at the head of the spur dyke is larger for the upward spur dyke. Soil sedimantation between the spur dyke and the scour of the head are minimal with the downward spur dyke. Additionally, these are further segregated into overflowing spur dykes depending if the discharge overflows the spur dykes. They may also be segretated in accordance with their structural material into concrete, concrete block, wet masonry, cylinder, and wood frame types, etc.

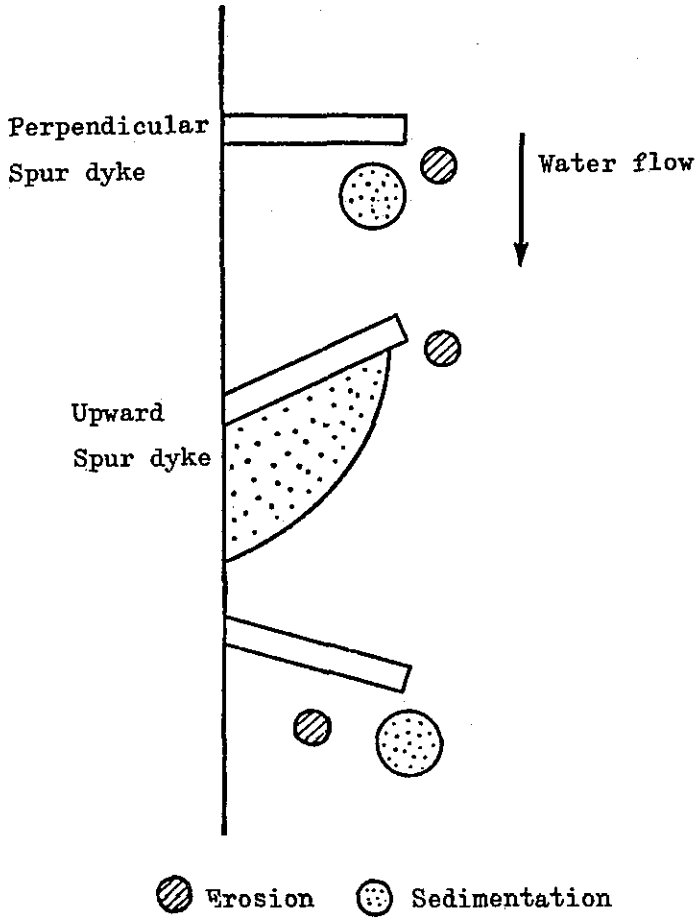


Diagram 4-32 Groine

(3) Type Selection

The type selection is generally performed as described next. In short streambank sliding areas in the upstream, downward and non-overflowing spur dykes are planned in the edge of the upstream of the land creeping area in order to isolate the current from the hillfoot to prevent the land creepage from expanding. Additionally, multiple perpendicular and non-overflowing spur dykes are planned when land creep areas exist for an extended length along the streambank. The erosion of the facing bank should also be considered since the planning is usually performed for one of the banks in land creeping areas.
Perpendicular and non-overflowing spur dykes are planned for the facing banks to face each other in soil sedimentation areas with wide streambeds where the movement of gravel and erosion of the bank are excessive by the turbulent flow and drift.

(4) Height

The height is generally designed so that the crown of the spur dyke does not become overflown during floods. Additionally, the crown is to be provided with 1/10 to 1/15 gradient from the bank towards the center of the flow. Furthermore, the foundation of the tips are to be buried deep and long into the streambank in order to prevent erosion of the head.

(5) Length & Clearance

The length of spur dyke is to be determined upon through investigatien of the channel and discharge conditions. Generally, it is designed short for wildstreams. Spur dykes are often provided continuously, and the clearance is to be determined with the length and direction of the spur dyke, the strength of the current and the streamed gradient taken into consideration. The clearance may be extended if the length of the groyne is long. The clearance is generally 1.5 to 2 times the length of the spur dyke. The clearance is reduced in the subsided bank of the curvature and is widened in the protruded bank.

3. Channel Works

(1) Objective

Turbulent flows become generated during floods causing excessive side and longitudinal erosion and may cause disasters in the soil sedimentation area downstream. Therefore, the work to erect structures to protect the bank and to secure the streambed by providing a constant flow channel to such streams in order to prevent these disasters is called channel work.

(2) Design

The channel work may become buried or destroyed when the work is executed in the upstream in the devastated condition. Therefore, soil conservation works are executed upstream to reduce the gravel run-off and restore the devastated land prior to the execution of this work. Furthermore, when extensive time is needed for the restoration of the devastated land or when urgency is required for the restoration of disasters, the channel work is planned by erecting a dam for soil conservation wear upstream.

(3) Gradient

Maintain the gradient line as linear as possible when determining the gradient line of channel work. Attain the largest curvature radius possible in the event that it must be curved.

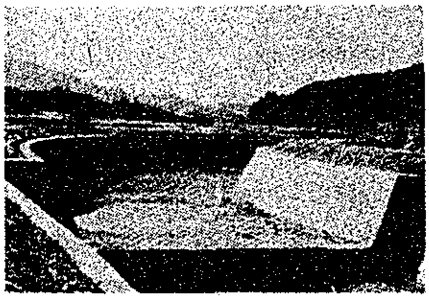


Diagram 4-33 Channel Work

Additionally, refrain from connecting curves with opposing directions and provide straight sections in between.
These factors must be thoroughly followed when the gradient is increased. The gradients of both banks must be parallel in order to avoid the rapid change of streamwidth. Furthermore, in the junction point of the main and tributary streams, the center line of these streams must be intercepted at a small angle since turbulent follows may be generated by the impact of the adjoining currents resulting in the devastation of the banks when this angle is large.

(4) Design Accumulating Gradient

Stable gradient are used for the design accumulating gradient to prevent soil sedimentation as well as erosion of the streambed upon completion of the channel work. This design accumulating gradient is designed generally at about 1/2 the original streambed gradient. The gradient may be constant from the beginning to the end of the channel work when the execution distance is short. However, the gradient must be varied where the upstream gradient is steep and becomes gentle towards the downstream when the construction distance is long. The difference between the existing and the design accumulating gradient is to be corrected with the head of the ground sill work. Multiple ground sill works with smaller heads should be designed in stead of a few large headed ground sill works at this point.

(5) Work Types

Sill bed work as well as triple side channel work, etc. are done as required by the condition of the stream along with the erection of revetment during channel work.

1) Stone Removal & Excavation

Large boulders on devastated streambeds are to be removed to determine the channel when executing channel work in accordance with the designed grading line. Additionally, the streambed soil must be excavated at times to form to designed channel section. This is done because it is safer to lower the riverbed than to erect embankments in channel work.

2) Ground Sill Work and Bed Gindle

Ground sill works are executed (along with bed gindles at times) the protection of the revetment as well as to prevent streambed erosion when executing channel work.

The wing of the ground sill work is to be sufficiently inserted into the ground in order to border the channel works.

This is done is order to prevent the damage to the downstream of the ground sill work in the event that a part of the channel work is destroyed. Additionally, in areas proved to large volume of subsurface water, in case that the destruction of the channel work may occure, drainage closed conduits are provided in addition to the ground sill work.

Bed Gindles are done for the purpose of fixation of original streambed and the reinforcement of retaining wall when the distance of the ground sill work is long, and may be thought of as headless ground will work. Therefore, the corwn of this work is to be aligned with the streambed during design.

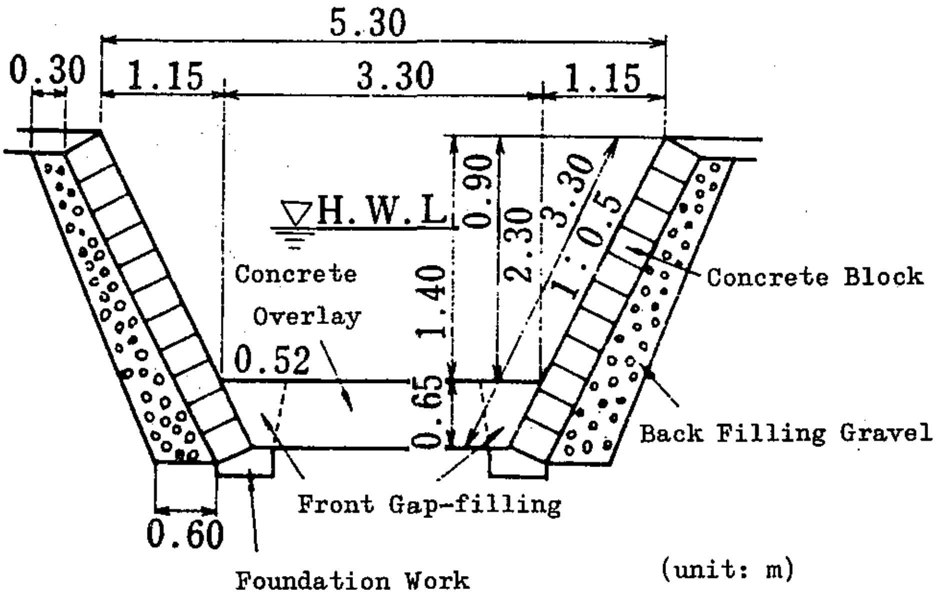


Diagram 4-34 Channel Work (Concrete Block)

3) Triple Side Pave Channel Work

The scouring advances when the streambed starts to settle and there is a danger of revetment destruction in narrow channel streams where the revetment foundations are almost in contact with each other. In such torrents, the streambed is secured with stone and concrete along with the construction of revetments. This is called the triple side paved channel work.

CHAPTER V LANDSLIDE (LANDCREEP) PREVENTION

SECTION 1 Landslide Investigation

Actual landslide conditions cannot be readily observed from the ground surface visually due to the cause being the generation of the sliding surface underground. Therefore, in order to achieve efficient landcreep prevention, the cause, extent, and movement conditions must be studied with the methods described in the following.

Landcreep investigations may be segregated into collection of existing date, weather research, topographic survey, geological survey, ground surface shift survey, sliding surface survey and ground water survey.

1. Existing Data Collection

Landslide occurence area often have a history of land movement, since the land in such areas are moved continuously or intermittently over extended periods of time. Therefore, it is necessary to primarily study the generation dates, extent, cause, and movement speeds through local tales, etc. in order to clarify the overall landslide.

2. Weather Research

Rainfall, earthquakes, and removed of slope bottoms are some of the known causes of landslides. However, it is also know that landslides frequent occur after rainfalls. This is due to high correlation between landslide shift and precipitation. Therefore, investigation of the precipitation is considered to be most important of all weather research aspects.

3. Topographic Survey

The extent and range of the landcreep may be observed on 1/25,000 or 1/50,000 scale topographical maps with exclusive creeping land features such as ununiformed contour lines, as well as increased numbers of SENMAIDA (thousand terraced fields) as illustrated in diagram 5-1, swamps, and ponds. These features are also helpful in location and detection of landcreep areas where potential landcreep phenomena are

P.132 Diagram 5-1 SENMAIDA (in Japan)
(Thousand terraced fields)

not yet evident. Following to the study of the map, the following are to be investigated in the actual landcreep area.

1) Positions of sunken and protruded topography.

2) Positions, directions, length, and width of cracks.

3) Movement direction of the creeping land.

4) Directions and positions of faults, if any.

5) Positions of ponds, swamps, marshland, and spring.

6) Positions of abnormaly phenomena such as heeled houses and trees as well as cracked roads, etc.

These investigation results are then inscribed into a 1/5000 scale topographical map which is to be utilized for the planning of landcreep prevention works.

4. Geological Survey

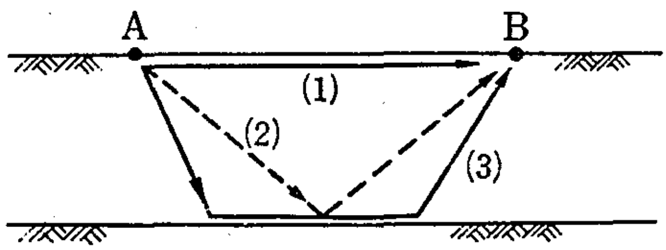
Cause and scope of the landcreep can also be estimated from detailed geological structure investigation since landcreep exhibit close relations with the geological structure of the topography, such as frequent generation in areas with particular types of geological structure. The following methods of survey are generally performed.

(1) On - Site Survey

The overall geological structure of the subject are may be reviewed by studying the geological structure chart. However, it is further necessary to survey the strike, incline, thickness, and existence of faults, etc. of the underlying rock at the site of the landcreep.

(2) Seismic Prospecting

This method of investigation employ the elasticity wave (earthquake wave) feature to change the transmittal speed while transmitted through the ground depending on the hardness of the geological structure. Therefore, the geological structure is determined with the measurement of the elasticity wave transmittal speed. Furthermore, the thickness of the stratum may also be determined by measuring the difference in the transmittal time, for the elasticity wave transmittal time varies depending on the direct, reflected, and refracted waves as illustrated in diagram 5-2.



(a) Direct Wave (b) Reflected Wave (c) Refracted Wave

Diagram 5-2 Seismic

Survey points are to be placed in lattice form through the subject area when performing the investigation.

(3) Electrical Prospecting Method

Geological structure may also be determined with this method which employs the electrical characteristic where the conductivity varies in accordance with the geological structure. Actual investigations

are accomplished by taking measurements of the electrical resistance (Specific resistance) between two points.
This electrical resistance investigation may be segregated into horizontal investigation where the two measurement points are established horizontally, and vertical investigation where the two points are vertically established. The former of the two is suitable for the location of the distribution of ground water. Furthermore, boring holes are used for the vertical investigation.
As with the seismic wave investigation, survey points are to be placed in lattice form throughout the subject area when performing the investigation.

(4) Natural Radiation Measurement

Vaporized Radon and Thoron are often found to be released from through the crust faults and fractured zones when such conditions are existent. Therefore, existence of such faults and fractured zones may be determined by measuring these natural radiations.

(5) Boring

This is a method where vertical holes are bored into the landcreep ground in order to obtain core samples for visual determination of the geological structure as illustrated in diagram.
Accurate results may be obtained with this method. However, it is necessary to employ this method in conjunction with other methods since it is highly costly and therefore prohibitive to bore throughout the subject area.

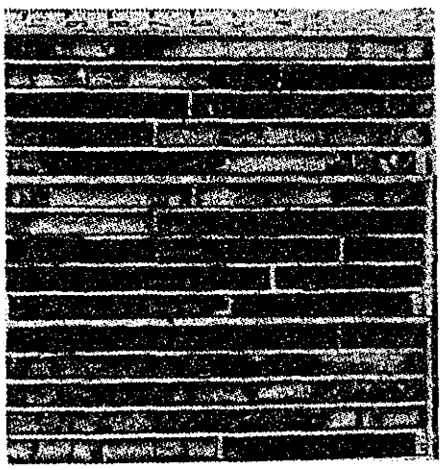


Diagram 5-3 Boring Core Samples

5. Ground Surface Shift Survey

To investigate and analyze the timing, volume, direction, and speed of the landcreep are highly useful for the prediction of landcreep generations as well as are essential data for the planning of landcreep prevention measures. Following methods are available for the landslide movement volume investigation.

(1) Surveying with Level Post

Landcreep volume may be measured with the placement of level post in the subject area and the measurements taken from them. Diagram 5-4 illustrates the placement of level post in rows and diagram 5-5 illustrates lattice form placement. Level post are to be placed throughout the subject area with the control point on immovable ground.

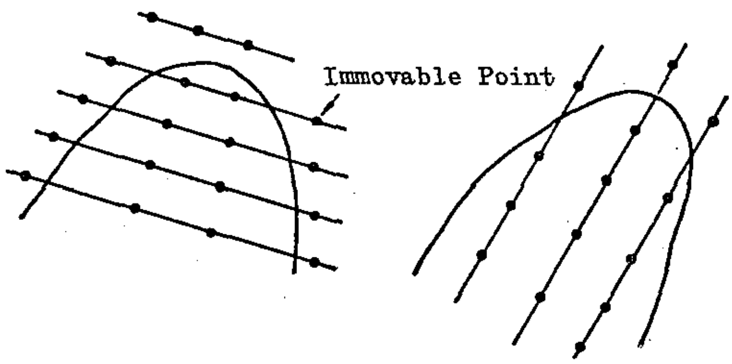


Diagram 5-4 Row Formed Level Post Placement

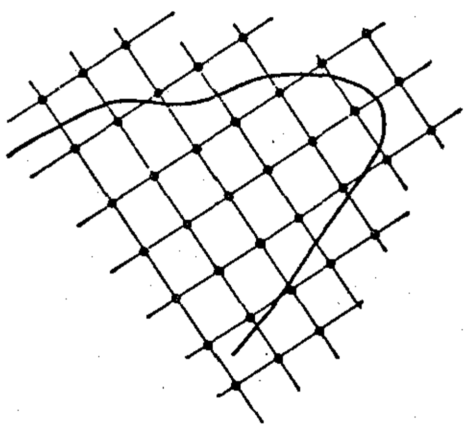


Diagram 5-5 Lattice Formed Level Post Placement

2) Expansion Gauge

Landcreep volumes may be determined by measuring the survey line expansion caused by the movement of the land, with expansion gauges placed in the vicinity of the landcreep area border. The expansion gauge is placed on immovable ground with poles driven in the subject landcreep area, normally in the stress cracked sections of the Crown of the landslide area with tension cracks along the movement direction.

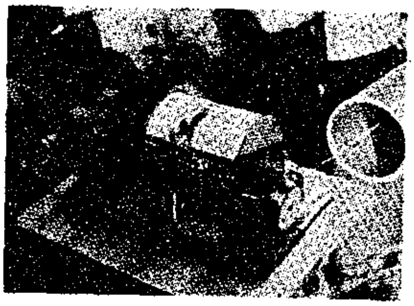


Diagram 5-6 Expansion Meter

(3) Tilting Gauge

Methods employing level posts and expansion gauges are methods where the landslide volume is measured directly, where as the method employing the tilting gauge is used for estimating the landslide volume indirectly with the change in the incline of the topography.
A pair of pneumatotubes are placed perpendicularly each other within the tilting gauge as illustrated in diagram 5-7. The movement of the bubbles within these pneumatotubes are measurable with the adjustment volume of the screw. The tilting gauge is suitable for measuring the minimal movements of the earth caused by the landslide.

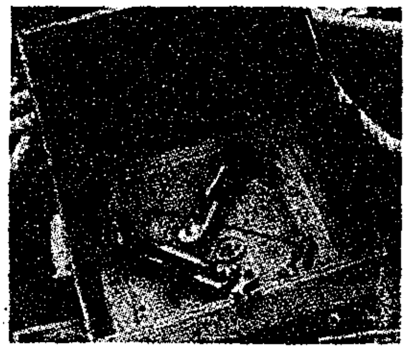


Diagram 5-7 Tilting Gauge

6. Sliding Surface Survey

The following methods are available for accurate means of the position of the sliding surface.

(1) Investigation by Boring

This is a method where the sliding surface is determined from the columnar section obtained by boring, and landcreep clay are generally foung in the sliding surface. Boring survey lines are established in the deepest estimated sliding surface, but is also desirable to be established beyond the landslide area for both ends of the boring line, in order to detect the existence of the latent sliding surface as illustrated in diagram 5-8.

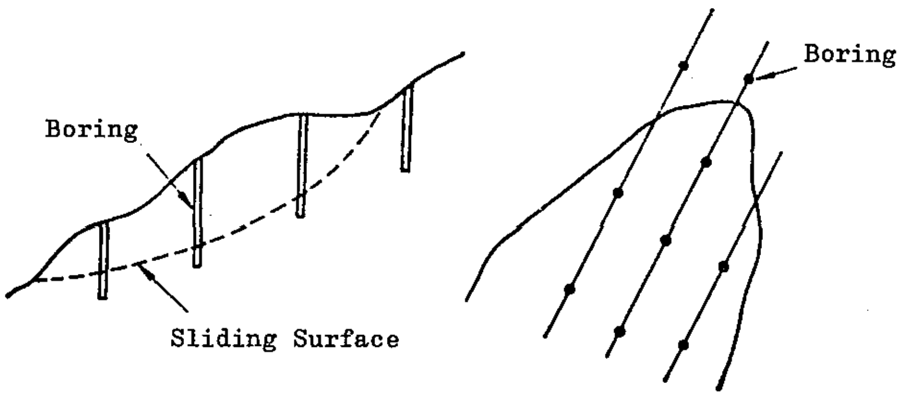


Diagram 5-8 Boring

(2) Investigation Using Strain Gauge

This is the method where the volume of strain is measured with electrical resistance strain gauge (Diagram 5-9) placed in the vicinity of the sliding surface using the boring hole. This method is suitable for measuring slight movements, and sliding surface position and its shift may be evidently observed as the measurement results are accumulated strain as seen in diagram;5-10.

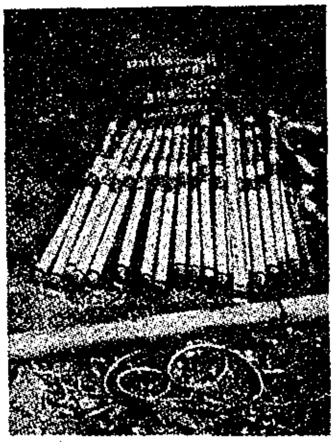


Diagram 5-9 Electrical Resistance Strain Gauge

7. Ground Water Survey.

Landslide are often caused with ground water. This is due to the increase of sliding surface pore water pressure caused by the elevation of the ground water level resulting in the reduction of the sliding plane resistance.
The following methods are available for ground water level survey.

(1) *Ground Water Level Survey*

Ground water levels and landslides exhibit close relations in accordance with various landslide data. Existing wells and boring holes are used for ground water level observation.
Additionally, the water level must be observed after every rainfall.
Observations are made by lowering ropes or with the installation of a self-recording water level gauge.

(2) Pore Water Pressure Gauge

Direct pore water pressure measurements may be taken with the installation of a pore water pressure gauge on the sliding surface. On the contrary, accurate pore water pressure measurements are scarce, since accurate installation of this equipment is difficult due to the thickness of the sliding surface being generally thin, as well as by the necessity to remove the earth pressure from the top. Therefore,

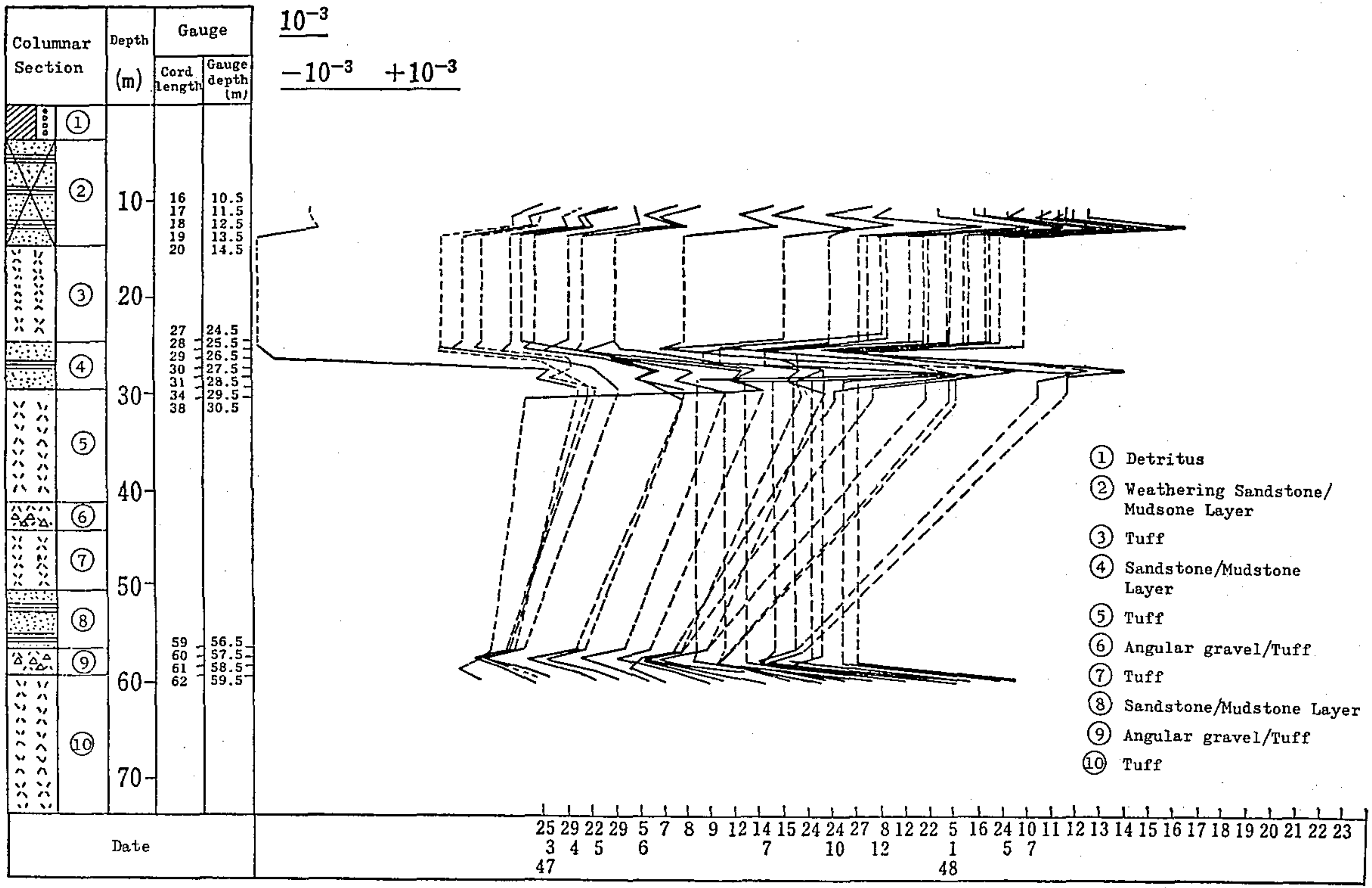


Diagram 5-10 Accumulated Strain Graph

pore water pressure are usually described with the ground water level.

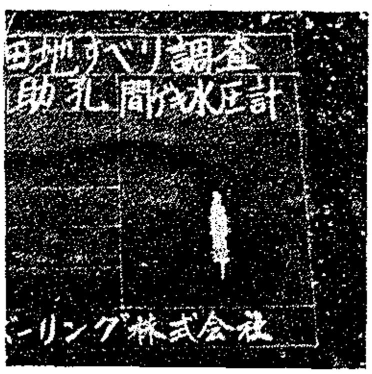


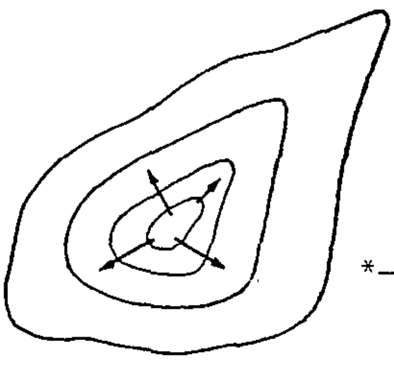
Diagram 5-11 Pore Water Pressure Gauge

(3) Conditions of Ground Water Flow

The following methods are available to determine the entry routes and distribution of ground water.

1) Ground Water Level Method

The flow conditions of ground water may be investigated by drawing ground water surface contour lines as illustrated in diagram 5-12 with water level measurements taken from existing wells and boring holes.



*⟶ are the directions of ground water flow.

Diagram 5-12 Ground Water Level Countour Line Schematic

(2) Chemical Substance Application Method

Ground water routes may be determined with the application of chemical substances in the upstream for detection of downstream, when ground water routes may be guessed from the topographical and geological structure conditions, etc. in the vicinity of the landslide area.

Pigment, ion and radiation detection methods are available depending on the employed chemicals.

Section 2 Landslide (Landcreep) Prevention Work

1. Slope Stabilization

Slipping and sliding surfaces of slopes are generally in the form of a curve.

Therefore, these slipping and sliding surfaces are often assumed to be in the form of arc in the calculations for landslide stabilization.

The following are the consideration for a single block taken from the landslide clod segregated into width units. (Diagram 5-13)

Now, with;

$\overset{\frown}{ABC}$: Sliding Surface

O : Center of the arc $\overset{\frown}{ABC}$

R : Radius

W : Soil weight per width unit

ℓ : Sliding surface length width unit

$\dot{U}$: Pore water pressure

θ : Angle where the B point tangent becomes horizontal

C : Sliding surface soil cohesion

ϕ : Internal friction angle of soil on the sliding surface

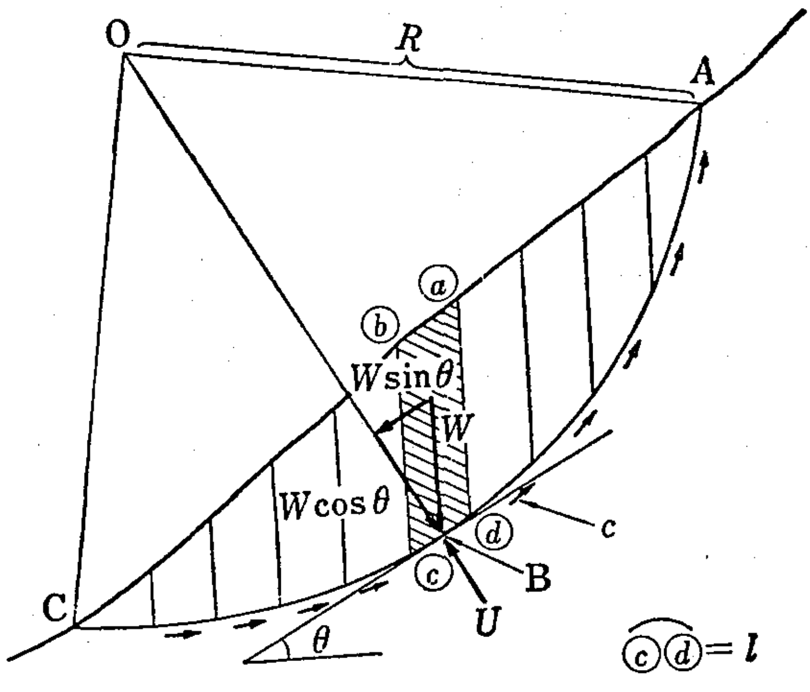


Diagram 5-13 Analysis for Slope Stabilization

The moment of the slippage generative force becomes:

(equation) $M_1 = RW \sin\theta$

and the slippage resistance moment become:

(equation) $M_2 = R\ \{(W \cos\theta - U) \tan\phi + cl\}$

Since the factor of safety is applicable for all of the blocks when the overall landcreep safety factor is F.S., it becomes:

(equation) $F.S. = \dfrac{\Sigma M_2}{\Sigma M_1} = \dfrac{\Sigma\{(W \cos - U) \tan\phi + cl\}}{\Sigma W \sin\theta}$

Therefore, the slope is stabilized when FS >1.0 and landslide occurs when FS <1.0.

W, l, and θ here are obtained on the graph, and U thru ground water investigation, as well as c and ϕ through soil shearing test.

2. Landslide Prevention Work Plans

Landslide prevention works are normally planned with safety factor between 1.1 - 1.2 with the methods described below.

1) By reducing (equation) $\Sigma M_1 = \Sigma RW \sin\theta$

2) By increasing (equation) $\Sigma M_2 = \Sigma R \{ W \cos\theta - U) \tan\phi + cl$

The following are landslide prevention works segregated in accordance with aforementioned principle.

- Prevention Works
  - Reduce ΣM_1
    - Dozing Work
  - Increase ΣM_2
    - Lowering of ground water level
      - Water Channel work
      - Closed Conduit Work
      - B ring Closed Conduit Work
      - Water Catchment Well Work
      - Tunnel Closed Conduit Work
      - Ground Water Isolation Work
    - Increasing of the resistance with artificial structures
      - Torrent Work
      - Retaining Work
      - Pile Driving Work

3. Types of Landslide Prevention Work

(1) Dozing Work

Efficient results may be attained by removing the top of the landslide slopes with dozing work as illustrated in diagram 5-14. However, it is suggested that this work should be executed during the dry season in conjunction with water way works since the ground water level may elevate excessively by rainfall and surface water infiltration.

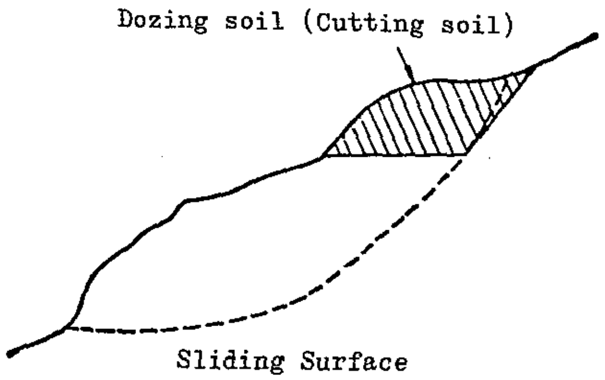


Diagram 5-14 Dozing Work

(2) Water Channel and Closed Conduit Works

Landslide slopes exhibit large numbers of tension and compression crack generations caused by the movement of the land as well as ponds and lakes where rain and surface water are often infiltrated. Therefore, it is urgently required to treat these water with water channel works. Additionally, flexible structures are employed in landslide areas since they may be destroyed by the movement of the land. Furthermore, closed conduit works intended for the drainage of near surface infiltration, are to be executed in conjunction with water channel works.

(3) Boring Closed Conduit Work

Boring closed conduit work are executed in places where ground water are distributed widely in shallow sections of the landslide terrain. It is important this is case to drain the water in the upper sections of the slope as illustrated in diagram 5-15. Additionally, large drainage effects may be attained by executing the work in a radial form through the sliding surface.

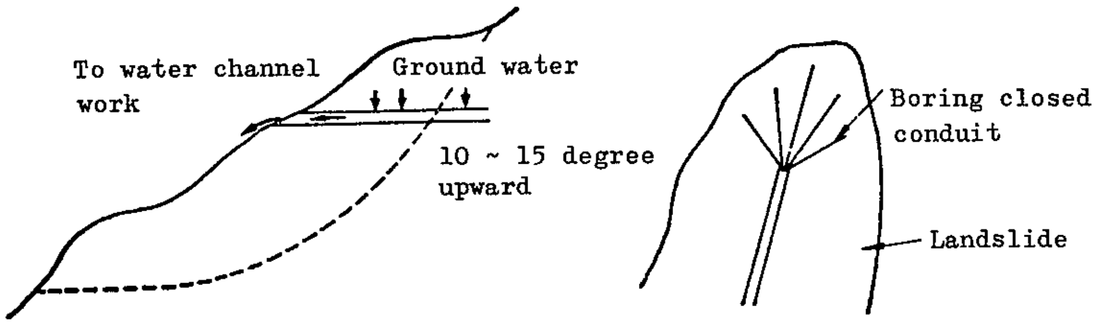


Diagram 5-15 Boring Closed Conduit Work

(4) Water Catchment Well Work

Water catchment wells are bored with boring applied from the sides for the catchment of water in areas where large volumes of ground waters exist in the form of water veins. The collected water is then drained by boring. There are water catchment wells made by methods such as concrete lining and liner plate inserting.

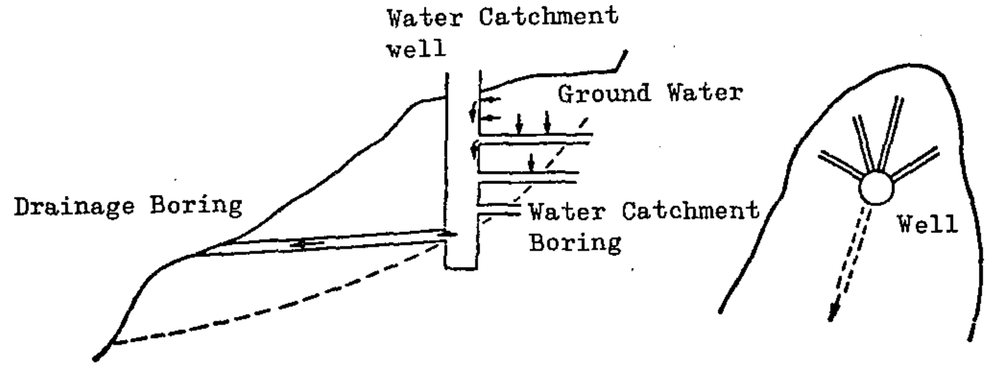


Diagram 5-16 Water Catchment Well

5) Tunnel Closed Conduit Work

Tunnel closed conduit works are executed in broad landslide areas where abundant ground water exist in the deep ground as illustrated in diagram 5-17. It is necessary to confirm the positions of the water veins before the execution since tunnel excavation in landslide areas are costly and hazardous. Moreover, tunnel excavations are required to be applied within rigid immovable terrain. Ground water are collected with horizontal and vertical borings spread out from the tunnel, and are then drained through the tunnel.

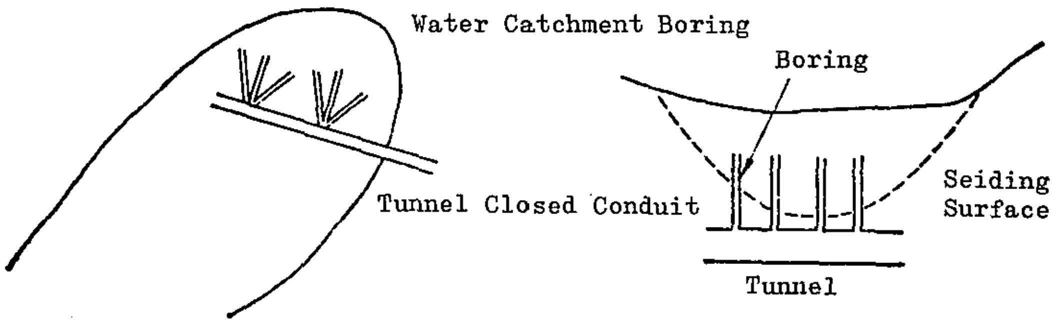


Diagram 5-17 Tunnel Closed Conduit Work

(6) Ground Water Isolation Work

Ground water entry into the landslide are isolated and drained with this work as illustrated in diagram 5-18 when the flow routes of ground water are known beforehand. Burial of concrete structures and insertion of mortar as well as chemicals are some of the methods for this work.

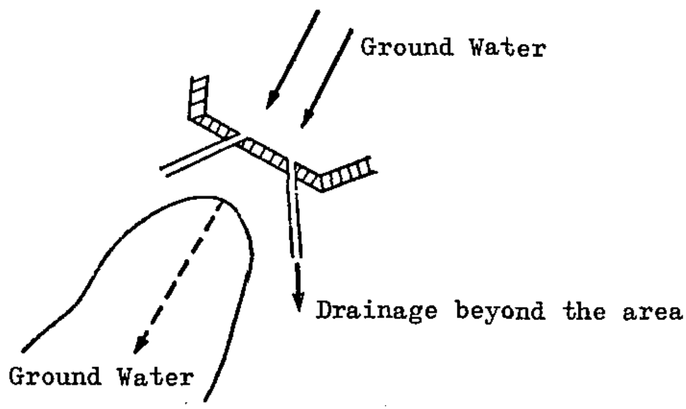


Diagram 5-18 Ground Water Isolation Work

(7) Torrent Work

Landslides generated along torrentside tend to become enlarged due to the falling of slopes caused by the foot attacking of run-offs. Therefore, it is necessary to protect the foot with the execution of revetment and spur dyke works. Additionally dam works are executed at times to form sediment on slope foot in order to attain landslide resistance effect with the sediment Diagram 5-19. Such dams are effective against minor landcreeps.

8) Retaining Work

This is a method where retaining works are applied to the end of the landslide in order to resist the earth pressure of the slope. It must be performed when planning this work to analyze the stability of the slope and calculate the size of the corresponding structure. Furthermore, this method is employed for minor and secondary landslide, for large stress cannot be expected with retaining works. Moreover, flexible structured retaining works such as cylinder and crib works are most suitable and widely used in landslide areas.

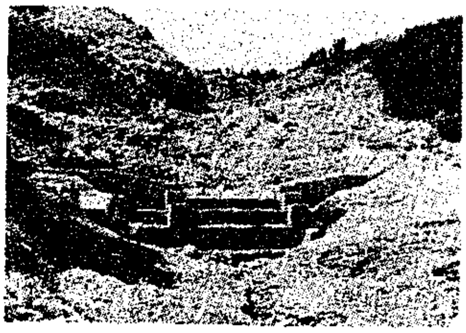


Diagram 5-19 Torrent Work Executed in Landslide Area

Pile Driving Work

This work is a method where piles are driven into the landslide ground to resist the landslide earth pressure with the resistance of the piles. It is important here that these piles be driven into immovable grounds. Additionally two or three rows of piles are normally driven in zigzag form. Positioning of the piles must be determined carefully since secondary sliding surface as illustrated in diagram 5-20 may be generated when the height of piles are too low or too high.

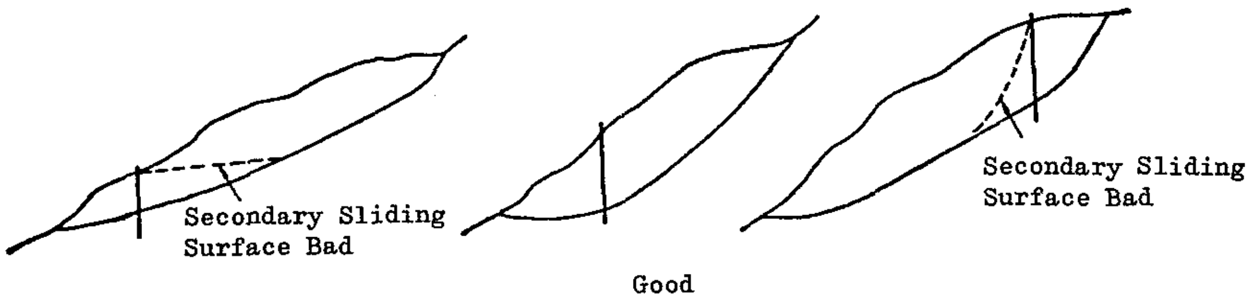


Diagram 5-20 Pile Positions

The following conditions must be fulfilled when designing the pile driving work.

1) Piles must be able to withstand the cantilever moment.

2) Piles must be able to withstand the shearing stress.

3) Soil around the pile must not become destroyed by shearing.

4) The foundation earth beneath the pile should not become destroyed.

Steel pipe, H framed steel, ferro concrete piles, and wood piles are the variations of piles, with steel pipes used most commonly.

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