JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF INFRASTRUCTURE
AND DEPARTMENT OF ROADS
THE GOVERNMENT OF MONGOLIA

# THE FEASIBILITY STUDY ON CONSTRUCTION OF EASTERN ARTERIAL ROAD IN MONGOLIA

## FINAL REPORT

## Vol. II: APPENDICES

JUNE 2002

PACIFIC CONSULTANTS INTERNATIONAL
JAPAN OVERSEAS CONSULTANTS

**THE FEASIBILITY STUDY**
**ON**
**CONSTRUCTION OF EASTERN ARTERIAL ROAD**
**IN**
**MONGOLIA**

**FINAL REPORT**

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# A. ATTENDANCE LIST

## A. Attendance List

Study Team

(1) Mongolian Steering Committee Members

| Name | | Position/Organization |
|---|---|---|
| Ts. Tsengel | Chairman | State Secretary of the MOI |
| J. Sereeter | Member | Director of the Roads, Transport, Info-communication and Tourism Policy Coordination Department, MOI |
| D. Naranpurev | Member | Director of International Cooperation Division of the State Administrative Management Department, MOI |
| H. Oyuntsetseg | Member | Department Director, MIT |
| D. Tsogtbaatar | Member | Vice Director of the Multilateral Cooperation Department, MFA |
| B. Erdenebaatar | Member | Director of the External Relations Division of the MJIA |
| R. Bud | Member | Director of the DOR |
| L. Chuluun | Member | Officer of the Economic Cooperation Department, MFE |
| L. Dolgormaa | Member | State Inspector, MNE |
| L. Gombo | Member | Head of the Planning and Research Division, DOR |
| B. Manduul | Secretariat | Officer of the Roads, Transport, Info-communication and Tourism Policy Coordination Department, MOI |

Notes: DOR (Department of Roads),
MFA (Ministry of Foreign Affairs),
MFE (Ministry of Finance and Economy),
MIT (Ministry of Industry and Trade),
MJIA (Ministry of Justice and Internal Affairs),
MNE (Ministry of Nature and Environment),
MOI (Ministry of Infrastructure),

(2) Mongolian Counterpart Team Members

| Name | | Position/Organization |
|---|---|---|
| G. Battogtokh | Team Leader/the Coordinator | Supervision Engineer of DOR |
| Ch. Bayasgalan | Bridge and Structure Engineer | Engineer of DOR |
| D. Ulziidelgel | Highway Engineer | Engineer of DOR |
| B. Oyunchimeg | Transport Economist | Engineer of DOR |
| D. Zagdradnaa | Pavement Specialist | Engineer of DOR |
| G. Narantuya | Regional Development Specialist | Engineer of DOR |
| B. Bayasgalan | Environmental Specialist | Staff of MNE |

Notes: DOR (Department of Roads),
MNE (Ministry of Nature and Environment)

(3) JICA Advisory Committee and Secretariat Members

| Name | | Position/Organization |
|---|---|---|
| Ken-ichiro OI | Chairperson | Director of Congestion Countermeasures Promotion Division, Planning Department, MEPC |
| Takumi HASHIMOTO | Member | Deputy Director, Second Road Planning Division, Road Department, Kinki Regional Department Bureau, MLIT |
| Toshio HIRAI | Secretariat | Director, First Development Study Division, Social Development Study Department, JICA |
| Yodo KAKUZEN | Secretariat | Deputy Director, First Development Study Division, Social Development Study Department, JICA |
| Rinko JOGO | Secretariat | Staff, First Social Development Study Division, Social Development Study Department, JICA |

Notes: MLIT (Ministry of Land, Infrastructure and Transport)
MEPC (Metropolitan Expressway Public Corporation)

(4) JICA Study Team Members

| Name | Assignment | Firm |
|---|---|---|
| Kenji MARUOKA | Team Leader | PCI |
| Tomoaki TAKEUCHI | Road Planning / Road Maintenance Planning | PCI |
| Takayuki HARA | Road Design | JOC |
| Yoshimi TAKAI | Bridge Planning / Bridge Design | PCI |
| Kimio KANEKO | Traffic Demand Forecast | PCI |
| Takashi INOUE | River / Hydrology | JOC |
| Osamu NOGOSHI | Topographic Survey | PCI |
| Hiroshi TANAKA | Environmental Assessment | PCI |
| Iwao YOKOKAWA | Geographic Survey / Natural Condition Survey | JOC |
| John SPURR | Economic Analysis | JOC |
| Hidetoshi NAKANO | Coordinator | PCI |

Notes: PCI: Pacific Consultants International
JOC: Japan Overseas Consultants

# B. ROAD

## B-1. Standard of Mongolia

### Table B-1 Levels of Service Criteria

| Level of Service | Volume to Capacity Ratio | | Traffic Volume per Lane per Hour | | Traffic Characterization | |
|---|---|---|---|---|---|---|
| | Two-Lanes | Multi Lanes | Two-Lanes | Multi Lanes | Two-Lanes | Multi Lanes |
| A<br>Highest Level | < 0.10<br>All Terrain Types | < 0.30 | <150 | < 650 | Nearly free flow and little restriction on passing, average speed above 90 km/hr. | Free traffic flow, vehicle density is below 6 per km. |
| B<br>High | 0.10-0.20<br>All Terrain Types | 0.30-0.45 | 150-240 | 650-800 | Vehicles move in groups, overtaking is with some restrictions, average speed over 80 km/hr. | Nearly free flow traffic, some vehicle interference, vehicle density below 10 per km |
| C<br>Average | 0.10-0.40<br>All Terrain Types | 0.45-0.60 | 240-600 | 800-1200 | Stable flow, vehicles move in large groups, overtaking is restricted, average speed over 70 km/hr. | Speeds are close to free flow, lane change restricted, vehicle density below 15 per km |
| D<br>Low | 0.40-0.70 Flat<br>0.40-0.60 Rolling<br>0.30-0.50 Mount. | 0.60-0.70 | 600-750 | 1200-1400 | Traffic flow approaching unstable, frequent traffic interruptions, low average speed. | Speeds begin to decline, drivers start experiencing discomfort, vehicle density below 20 per km. |
| E<br>Very Low | 0.70-1.00 Flat<br>0.60-1.00 Rolling<br>0.50-1.00 Mount. | 0.70-1.00 | 750-1200 | 1400-2000 | Forced unstable flow | Traffic approaching unstable, density close to 25 vehicles per km |
| F<br>Failure | 1.00<br>All Terrain Types | 1.00 | 1200 | 2000 | Forced unstable flow, average speed below 50 km. | Forced unstable flow |

**Table B-2 Technical Classfication**

| | |
|---|---|
| Highways with restricted access | When access connections are by means of grade-sparated interchanges with a limited number of selected public roads. |
| Highways with partially restricted access | Achieved either by means of grade-separation structures or through at-grade intersections such that preference is given to through traffic. Grade-separated railway crossings are mandatory as part of partial access control. |
| Conventional Highways | With no restrictions on access in most cases. |

**Table B-3 Classification by design type**

| | | |
|---|---|---|
| Freeways | | Accommodate movements of large traffic volumes, over long distances, at high speeds and under free flow condition. Designed as multi-lane divided highways with restricted access, these facilities provide the highest level of service. |
| Expressways | | Accommodate movements of large traffic volumes at high speeds. Designed as multi-lane divided highways with partial access control and compulsory grade-separated railway crossings, these facilities assure a high level of service. |
| Conventional Highways | | As a rule, has no restrictions on access and are comprised of two basic groups |
| | Multi-lane Highways | With more than two traffic lanes, can serve a wide range of traffic volumes, can be divided or undivided, and depending on the initial design, can be converted into higher level facilities such as high-speed highways and freeways. Partial access control may be warranted on some road sections to maintaine adequate level of service. |
| | Two-lane Highways | Are flexible facilities in terms of their functional purpse and a range of design speeds but limited in terms of traffic capacity. When traffic volumes warrant, truck climbing lanes are provided. |
| Low Volume Roads | | Primarily serve traffic to and from isolated communities, recreational sites and resource development areas. Depending on the specific function, these roads are designed as one or two-lane facilities, generally, suitable for operation as slow sppeds. |

**Table B-4 Pavement Cross Slopes**

| Climatic Zone | | I | II | III | IV | V |
|---|---|---|---|---|---|---|
| Multi-lane Highways | | | | | | |
| | Two-way Cross-slopes | 0.015 | 0.020 | 0.020 | 0.025 | 0.015 |
| One-way Cross-slopes | | | | | | |
| | First and second lane form the median | 0.015 | 0.020 | 0.020 | 0.020 | 0.015 |
| | Third and subsequent from the median | 0.020 | 0.025 | 0.025 | 0.025 | 0.020 |
| Two-lane Highways | | 0.020 | 0.020 | 0.020 | 0.020 | 0.015 |

**Table B-5 Pavement Cross-slopes for Low Volume Roads**

| Surfacing Type | Cross-slope (m/m) |
|---|---|
| Surfaced Roads | 0.02-0.04 |
| Gravel, Aggregate | 0.04 |
| Earth | 0.04 |

Note: Shoulder cross-slopes for low volume roads should not be less than values indicated in table 6.

**Table B-6 Cross-slopes for Shoulder**

| Surfacing Type | Cross-slope (m/m) |
|---|---|
| Concrete | 0.02-0.04 |
| Bituminous Surfacing | 0.03-0.04 |
| Gravel, Aggregate Surfacing | 0.04-0.06 |

Shoulder cross-slopes for crown sections should be 0.01-0.03 m/m greater than the roadway cross-slope.

**Table B-7 Pavement cross-slopes on superelevated sections**

| Horizontal curve radius (m) | Superelevation (‰) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 140 | 120 | 100 | 80 | 60 | 50 | 40 | 30 |
| 6000-5500 | 20 | | | | | | | |
| 5500-5000 | 20 | 20 | | | | | | |
| 5000-4500 | 30 | 20 | 20 | | | | | |
| 4500-4000 | 30 | 20 | 20 | | | | | |
| 4000-3500 | 40 | 30 | 20 | | | | | |
| 3500-3000 | 40 | 30 | 20 | | | | | |
| 3000-2500 | 40 | 30 | 20 | | | | | |
| 2500-2000 | 50 | 40 | 20 | 20 | | | | |
| 2000-1500 | 60 | 40 | 30 | 20 | | | | |
| 1500-1000 | 60 | 50 | 40 | 20 | 20 | | | |
| 1000-900 | | 60 | 50 | 30 | 20 | 20 | | |
| 900-800 | | 60 | 50 | 30 | 20 | 20 | | |
| 800-700 | | 60 | 50 | 40 | 20 | 20 | | |
| 700-600 | | | 60 | 40 | 30 | 20 | | |
| 600-500 | | | 60 | 40 | 30 | 20 | 20 | |
| 500-400 | | | 60 | 50 | 30 | 20 | 20 | |
| 400-450 | | | 60 | 60 | 40 | 30 | 20 | |
| 450-300 | | | | 60 | 40 | 30 | 20 | |
| 300-250 | | | | 60 | 50 | 40 | 30 | 20 |
| 250-200 | | | | 60 | 50 | 40 | 30 | 20 |
| 200-150 | | | | | 60 | 50 | 30 | 20 |
| 150-100 | | | | | 60 | 60 | 40 | 30 |
| 100-75 | | | | | | 60 | 50 | 40 |
| 75-50 | | | | | | | 60 | 50 |
| 50-30 | | | | | | | 60 | 60 |

**Table B-8 Minimum Radius of Horizontal Curves not Requiring Superelevations**

| Design Speed (km/h) | Minimum Radius (m) |
|---|---|
| ≦60 | 900 |
| 80 | 1300 |
| 100 | 2700 |
| 120 | 4600 |
| 140 | 7500 |

**Table B-9 Superelevation Run-off**

| Road Type | Run-off (‰) |
|---|---|
| Multi-lane Highways | 5 |
| Two-lane Highways in level terrain | 10 |
| Two-lane Highways in Mountain Terrain | 20 |

**Table B-10 Length of Superelevation Runoff**

| Circular Curve Radius (m) | 250 | 300 | 400 | 500 | 600-1000 | 1000-5000 |
|---|---|---|---|---|---|---|
| Length of Trasition Curve (m) | 80 | 90 | 100 | 110 | 120 | 100 |

## Table B-11 Lane Winding on Horizontal Curves

| Curve Radii (m) | Rear Axle (m) | | | | |
|---|---|---|---|---|---|
| | All Vehicles | Combination Trucks | | | |
| | <7 | <11 | <13 | <15 | <18 |
| 1000 | - | - | - | - | 0.4 |
| 850 | - | - | 0.4 | 0.4 | 0.5 |
| 650 | 0.4 | 0.4 | 0.5 | 0.5 | 0.7 |
| 575 | 0.5 | 0.5 | 0.6 | 0.6 | 0.8 |
| 425 | 0.5 | 0.5 | 0.7 | 0.7 | 0.9 |
| 325 | 0.6 | 0.6 | 0.8 | 0.9 | 1.1 |
| 225 | 0.8 | 0.8 | 1.0 | 1.0 | 1.5 |
| 140 | 0.9 | 0.9 | 1.4 | 1.5 | 2.2 |
| 95 | 1.1 | 1.1 | 1.8 | 2.0 | 3.0 |
| 80 | 1.2 | 1.2 | 2.0 | 2.3 | 3.5 |
| 70 | 1.3 | 1.3 | 2.2 | 2.5 | - |
| 60 | 1.4 | 1.4 | 2.8 | 3.0 | - |
| 50 | 1.5 | 1.5 | 3.0 | 3.5 | - |
| 40 | 1.8 | 1.8 | 3.5 | - | - |
| 30 | 2.2 | 2.2 | - | - | - |

## Table B-12 Length of prolonged grades in mountainous terrain

| Longitudinal Grade (%) | Section Length (m) with altitude above sea level (m) | | | |
|---|---|---|---|---|
| | 1000 | 2000 | 3000 | 4000 |
| 6.0 | 2500 | 2200 | 1800 | 1500 |
| 7.0 | 2200 | 1900 | 1600 | 1300 |
| 8.0 | 2000 | 1600 | 1500 | 1100 |
| 9.0 | 1500 | 1200 | 1000 | - |

## Table B-13 Maximum Length of Tangents between Curves

| Road Category | Ultimate Length of Straight Line in Plan in Area (m) | |
|---|---|---|
| | Flat Area | Rolling Terrain |
| Multi-lane Highway | 3500-5000 | 2000-3000 |
| Two-lane Highway | 2000-3500 | 1500-2000 |
| Low Volume Road | 1500-2000 | 1500 |

## Table B-14 Curve Radii for Small Angle of Change in Horizontal Alignment

| Angle of Turn (Deg) | 1 | 2 | 3 | 4 | 5 | 6 | 7-8 |
|---|---|---|---|---|---|---|---|
| Minimum Curve Radius (m) | 30,000 | 20,000 | 10,000 | 6,000 | 5,000 | 3,000 | 2,500 |

## Table B-15 Maximum Length of Longitudinal Straits between Vertical Curves for Two-lane Highway

| Radius of Sag Vertical | Algebraic Difference of Longitudinal Grades (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 8.0 | 10.0 |
| 2,000 | 120 | 100 | 50 | 0 | 0 | 0 | 0 |
| 6,000 | 550 | 440 | 320 | 220 | 140 | 60 | 0 |
| 10,000 | - | - | 680 | 600 | 420 | 300 | 200 |
| 15,000 | - | - | - | - | - | 800 | 600 |

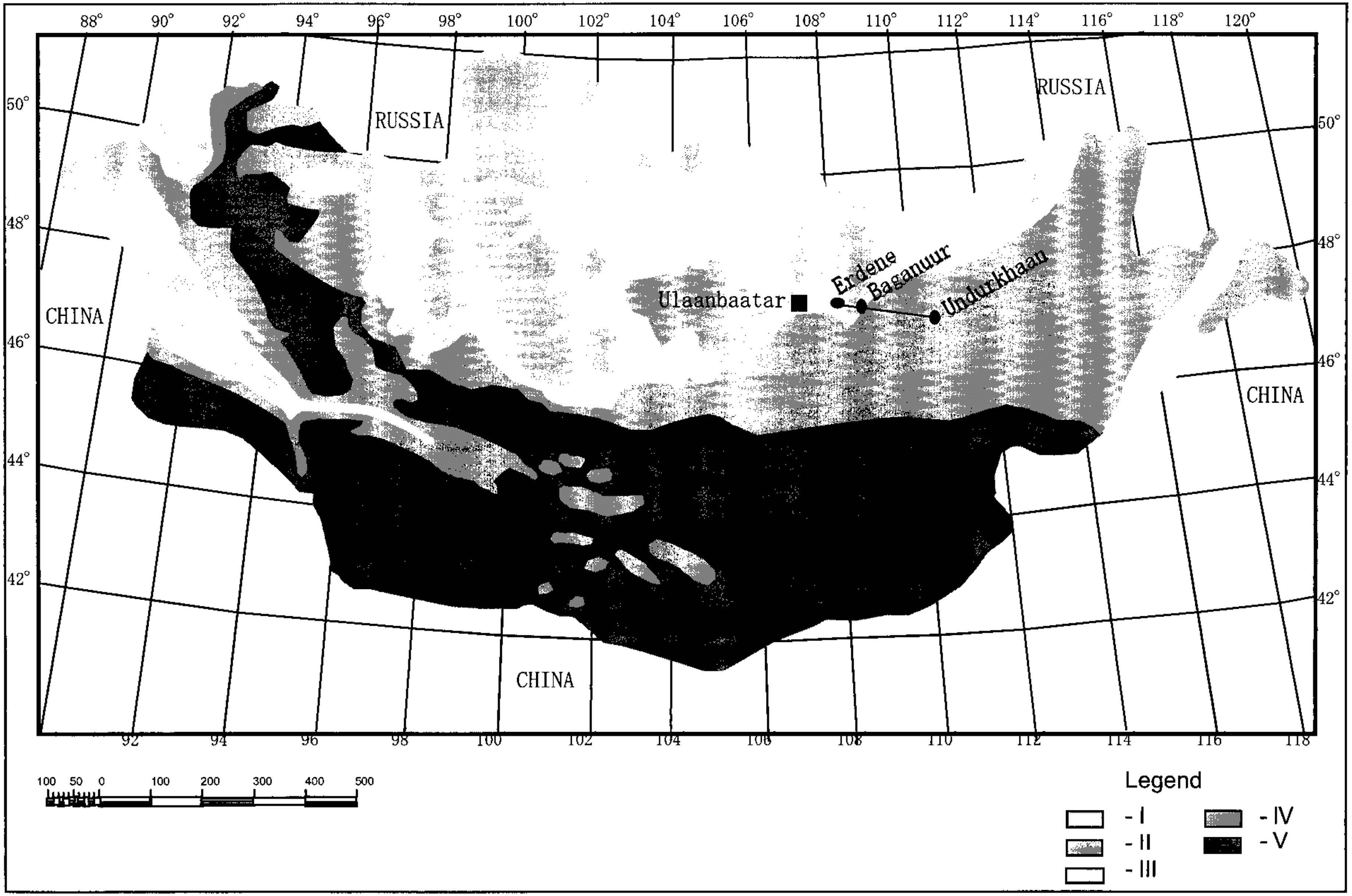


**Figure B-1 Euro-Asian Road Climatic Zone**

## Table B-16 Minimum Pavement Elevation above Ground Water Level

| Soil of the Active Subgrade Layer | Minimum Rise of the Pavement Surface by Climatic Zone (m) | | | |
|---|---|---|---|---|
| | II | III | IV | V |
| Fine sand, lightweight coarse sandy loam, lightweight sandy loam | 1.1 | 0.9 | 0.75 | 0.5 |
| | 0.9 | 0.7 | 0.55 | 0.3 |
| Silty sand, silty sandy loam | 1.5 | 1.2 | 1.1 | 0.8 |
| | 1.2 | 1 | 0.8 | 0.5 |
| Heavy loam, clays | 2.2 | 1.8 | 1.5 | 1.1 |
| | 1.6 | 1.4 | 1.1 | 0.8 |
| Heavy silty sandy loam, lightweight silty loam, heavy silty loam | 2.4 | 2.1 | 1.8 | 1.2 |
| | 1.8 | 1.5 | 1.3 | 0.8 |

Notes:

1. Above line: rise of the pavement surface above the groundwater table, perched water table of standing surface water level (for more than 30 days).
2. under line: rise of the pavement surface above the earth surface at locations where surface run-off is inhibited or above standing surface water level (for less than 30 days).
3. In permanently irrigated regions the rise of the pavement surface above the winter and spring groundwater levels should by increased by 0.4 m for climatic zones IV and V and by for the climatic zone III.

## Table B-17 Minimum Embankment Height against Drifting Snow

| Road Type | Minimum Embankment Height |
|---|---|
| All multi-lane highway excluding roads of category II | 1.2 m |
| Category II | 0.7 m |
| Category III | 0.6 m |
| Category IV | 0.5 m |
| Low volume roads | 0.3 - 0.4 m |

## B-2. Comparison of Typical Cross Section and Geometric Design Criteria

**Table B-18 Comparison of Typical Cross Section by Donor**

| | | Mongolian Standard | | Asian Highway (ADB) | Japanese Standard | AASHTO |
|---|---|---|---|---|---|---|
| Highway Classification | | III | IV | Class II | I-3 | Rural Arterial |
| Number of Lanes | | 2 lanes | | 2 lanes | more than 2 lanes | Depend on Volume |
| Design speed | | 100-50 | 80-40 | 80-40 | 100-60 | 120-60 |
| Width (m) | Right of way | 50 | | 40 | - | - |
| | Lane | 3.5 | 3 | 3.5 | 3.5 - 3.0 | 3.6-3.3 |
| | Shoulder | 1.5-2.5 | 1.5-2.0 | 2-2.5 | 2.5 -1.25 | 1.2-2.4 |
| | Median strip | N/A | N/A | N/A | 3.0 - 2.25 | 3-2.25* |
| Pavement cross slope (%) | | 2 | | 2 | 1.5 - 2.0 | 1.5-3.0 |
| Shoulder cross slope (%) | | 4.0 - 6.0 | | 3.0-6.0 | 2.0 | 4.0-6.0 |
| Type of Pavement | | - | | Asphalt Concrete or Cement Concrete | Asphalt Concrete or Cement Concrete | - |

Note: It is applied in case of 4 lane road and more

**Table B-19 Comparison of Typical Cross Section by Project**

| Project Name | | Erdene-Baganuur A501 | | The Project for Road Construction Utilizing Rock Asphalt in Mongolia | Roads Development Project | Second Roads Development Project |
|---|---|---|---|---|---|---|
| Donor | | DOR | | Japan's Grant Aid | ADB | ADB |
| Section | | Erdene-Baganuur | Baganuur-Undurkhaan | Nalaih-Erdene | Ulaanbaatar-Darhan-Altanbulag | Naliah - Choir |
| Highway Classification | | - | - | III (Former) | - | III |
| Number of Lanes | | 2 lanes | 2 lanes | 2 lanes | 2 lanes | 2 lanes |
| Design speed | | - | - | 100-50 | - | 100-50 |
| Width (m) | Right of way | 100 | 100 | - | - | 100-15 |
| | Lane | 3.5 | 3.0 | 3.5 | 3.0 | 3.5 |
| | Shoulder | 2.5 | 1.0 | 2.5 | 2.0 | 1.5 |
| | Median strip | N/A | N/A | N/A | N/A | N/A |
| | Total | 12.00 | 8.0 | 12.00 | 10.0 | 10.0 |
| Pavement cross slope (%) | | 2.0 | 3.0 | 2.0 | 2.5 | 2.0 |
| Shoulder cross slope (%) | | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Type of Pavement | | Asphalt | Asphalt | Rock Asphalt | Asphalt | DBST and Asphalt |
| Project Name | | Darhan - Erdenet Road Project | Feasibility Study for Erdenet - Bulgan - Moron Road Project | Transport Development Subproject | | |
| Donor | | Kuwait Fund | Kuwait Fund | WB | | |
| Section | | Darhan - Erdenet | Erdenet -Bulgan - Moron | Erdenesant - Arvaikheer | Harhorin –Tsetesrlag | Tsetserlag –Undurulaan - Tosontsengel |
| Highway Classification | | - | III | - | - | - |
| Number of Lanes | | 2 lanes | 2 lanes | 2 lanes | 2 lanes | 2 lanes |
| Design speed | | 100-40 | 100-50 | - | - | - |
| Width (m) | Right of way | - | - | - | - | - |
| | Lane | 3.0 | 3.5 | 3.5 | 4 | 3 |
| | Shoulder | 1.5 | 1.5 | 2.5 | 1 | 1 |
| | Median strip | N/A | N/A | N/A | N/A | N/A |
| | Total | 9.0 | 10.0 | 12.0 | 10 | 8 |
| Pavement cross slope (%) | | 2.5 | 2.5 | 2.5 | 4 | 3 |
| Shoulder cross slope (%) | | 4.0 | 4.0 | 4.0 | 4 | 4 |
| Type of Pavement | | Asphalt | DBST | Asphalt | Gravel | Gravel |

Note: DBST means Double Bituminous Surfacing Treated.

## Table B-20 Comparison of Geometric Design Criteria by Donor

| Donor | Highway Classification | Number of Lanes | Terrain | Design speed | Min. horizontal curve (m) Desirable | Min. horizontal curve (m) Absolute | Max. vertical grade (%) Absolute | Max. vertical grade (%) With limited length | Max. superelevation (%) |
|---|---|---|---|---|---|---|---|---|---|
| Mongolian Standard | III | 2 | F | 100 | - | 450 | 5.0 | 7.0 (1900m) | 6.0 |
| | | | R | 80 | - | 250 | 6.0 | 8.0 (1600m) | |
| | | | M | 50 | - | 100 | 8.0 | 9.0 (1200m) | |
| | IV | 2 | F | 80 | - | 250 | 6.0 | 8.0 (1600m) | 6.0 |
| | | | R | 60 | - | 150 | 7.0 | 9.0 (1200m) | |
| | | | M | 40 | - | 60 | 9.0 | - | |
| Asian Highway | Class II | 2 | L | 80 | - | 210 | 4.0 | - | 10.0 |
| | | | R | 60 | - | 115 | 5.0 | - | |
| | | | M | 50 | - | 80 | 6.0 | - | |
| | | | S | 40 | - | 50 | 7.0 | - | |
| Japanese Standard | I-3 | More than 2 lanes | L | 100 | 700 | 460 | 3.0 | 4.0 (700m) | 10.0 |
| | | | M | 80 | 400 | 280 | 4.0 | 5.0 (600m) | |
| | | | SC | 60 | 200 | 150 | 5.0 | 6.0 (500m) | |
| AASHTO | Rural Arterials | Depend on Volume | L | 110-100* | - | 330-415 | 3.0 | - | 12.0 |
| | | | R | 80-100* | - | 195-330 | 4.0-5.0 | - | |
| | | | M | 80-60* | - | 105-195 | 7.0-8.0 | - | |

Note:
*Design Speeds in the higher range, the design speeds is normally used.

## Table B-21 Comparison of Geometric Design Criteria by Project

| Project Name | Donor | Length (km) | Highway Classification | Number of Lanes | Terrain** | Design speed | Min. horizontal curve (m) Desirable | Min. horizontal curve (m) Absolute | Max. vertical grade (%) Absolute | Max. vertical grade (%) with limited length | Max. superelevation (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| The Project for Road Construction Utilizing Rock Asphalt in Mongolia | Japan's Grant Aid | 31.1 | III (Former) | 2 | All | 100-50 | - | 100 | 5.0 | | 10.0 |
| Second Roads Development Project | ADB | 200.0 | III | 2 | F | 100 | *2700 | - | 5.0 | - | 6.0 |
| | | | | | R | 80 | *1300 | - | 6.0 | - | |
| | | | | | M | 50 | *900 | - | 8.0 | - | |
| Darhan - Erdenet Road Project | Kuwait Fund | 180.0 | - | 2 | S | 100-85 | 550 | 350 | 5.0 | - | 6.5 |
| | | | | | R | 70-60 | 220 | 150 | 6.0 | - | 7.0 |
| | | | | | M | 50-40 | 100 | 60 | 8.0 | - | 6.0 |
| Feasibility Study for Erdenet - Bulgan - Moron Road Project | Kuwait Fund | 397.0 | III | 2 | F | 100 | - | 450 | 5.0 | 7.0 (1900m) | 6.0 |
| | | | | | R | 80 | - | 250 | 6.0 | 8.0 (1600m) | |
| | | | | | M | 50 | - | 100 | 8.0 | 9.0 (1200m) | |

Note:
* Horizontal curve radius is preferable
** F is flat, L is level, R is rolling, M is mountainous, S is steppe and SC is Special Case.

## B-3 Proposed Design Criteria

(1) Sight Distance

Stopping sight distance is the sum of two distances:

- The distance traversed by the vehicles from the instant that the driver sights as object necessitating a stop to the instant that the brakes are applied (Brake Reaction Time); and
- The distance required to stop the vehicle the brake from the instant that brake application begins (Braking Distance).

2.5 seconds is used for the former and the later is dependent on the initial speed and the coefficient of friction between tires and pavement.

The following equation is used for the calculation of stopping sight distance:

$$D = 0.694 \times V + 0.00394 \times V^2 / f$$

where D : Stopping Sight Distance (m)

V : Initial Speed (km/h)

f : Coefficient of Friction between Tires and Pavement

Stopping sight distances by each design speeds on the wet condition are shown in Table B-22.

**Table B-22 Stopping Sight Distance on Wet Pavement**

| Design Speed (km/h) | Initial Speed | | Friction Coefficient on Wet Pavement | Stopping Sight Distance (m) |
|---|---|---|---|---|
| | % | km/h | | |
| 60 | 100 | 60 | 0.33 | 85 |
| 80 | 100 | 80 | 0.30 | 140 |
| 100 | 100 | 100 | 0.29 | 205 |
| 120 | 100 | 120 | 0.28 | 285 |

AASHTO recommends the minimum passing sight distance of 407 m for Vd = 60 km/h. If the design speed should increase up to 80 km/h, it would have to extend to 541 m or more.

Either passing sight distances could not be applicable on mountainous and rolling terrain because volume of cutting or filling should expand considerably due to applying lager vertical curve, and accordingly no passing / overtaking is adopted for the Study.

Sight distance is defined as the distance along a roadway that as object of specified height is continuously visible to the driver with eye-height above the road surface. The height of 1.2 m of driver's eye height is recommended by the HDSM and it is also specified in the Japanese Standard. The object height ranges from 0.1 m to 0.2 m in international standards.

0.2 m is used as the object height for the Study, which is specified by HDSM. Table B-23 tabulates the object and driver's eye height specified in the AASHTO and other standards.

As far as the Study may concern, only the design element of minimum vertical curve length is affected by this value.

**Table B-23 Summary of Object and Eye Height Specified**

| | Japan | AASHTO | HDSM | The Study |
|---|---|---|---|---|
| Driver's Eye Height for Stopping (m) | 1.2 | 1.07 | 1.2 | 1.2 |
| Object Height (m) | 0.1 | 0.15 | 0.2 | 0.2 |

Vehicles frequently overtake slower moving vehicles on 2-lane two ways highway such as the Eastern Arterial Road. The passing must be accomplished on lanes regularly used by opposing traffic. In flat terrain, passing sight distances are secured because of no suddenly change of vertical alignment.

(2) Maximum Superelevation ($i_{max}$), Minimum Radius ($R_{min}$) and Value of Superelevation on Curvature (i)

These three factors, $i_{max}$, $R_{min}$ and i are related each other together with the design speed. The design speeds of 100, 80 and 60 km/h is recommended as discussed previously to the Eastern Arterial Road.

The relation between minimum radius and maximum superelevation is calculated from the following formula.

$$R = \frac{Vd^2}{127 \times (i + f)}$$

where R : Radius (m)

Vd : Design Speed (km/h)

i : Superelevation (m/m)

f : Side Friction Factor

The side friction factors of 0.12 for 100 km/h, 0.14 for 80 km/h and 0.15 for 60 km/h are selected as the maximum allowable value in AASHTO, considering comfort of drivers and traffic safety.

Absolute maximum side friction factor of 0.4 on wet pavement may be used in order to check the safety on curves assuming that a vehicle is being operated at an excessive speed (20 km/h higher than the design speed i.e. Vd = 120 km/h, when design speed is

100 km/h as shown in Table B-24)

On the other hand, absolute maximum side friction factor of 0.1 on freeze condition may be used in order to check the safety on curves assuming that a vehicle is being operated at a moderate speed (10 km/h lower than the design speed i.e. Vd = 90 km/h, when design speed is 100 km/h as shown in Table B-24.)

**Table B-24 Maximum Superelevation and Minimum Radius**

| Design Speed (km/h) | 100 | 80 | 60 |
|---|---|---|---|
| Max. Allowable Side Friction Factor (f) | 0.12 | 0.14 | 0.15 |
| Max. Superelevation ($i_{max}$ : %) | 6.0 | | |
| Minimum Radius (m) | 450 | 250 | 150 |
| Side Friction Factor if 20 km/h higher than Vd | 0.20 | 0.25 | 0.31 |
| Absolute Max. Side Friction Factor on Wet Pavement | 0.4 | | |
| Side Friction Factor if 10 km/h lower than Vd | 0.086 | 0.093 | 0.086 |
| Absolute Max. Side Friction Factor on freeze condition | 0.1 | | |

The side friction factors f = 0.12 (100 km/h), 0.14 (80 km/h) and 0.15 (60 km/h) and resulting maximum superelevation $i_{max}$ = 6.0 % are also justified to be applicable to the rural road.

Crossfall of 2.0 % applicable to traveled way is mainly determined by drainage requirements. The minimum curvature, which requires superelevation, is determined by setting consistently low friction factor values, considering the effect of crossfall. Side friction factor of 0.035 recommended in the Japanese Standard are used to determine sharpest curve without superelevation as shown in Table B-25.

**Table B-25 Sharpest Curve without Superelevation**

| Design Speed (km/h) | 100 | 80 | 60 |
|---|---|---|---|
| Side Friction Factor (f) | 0.035 | | |
| Crossfall (%) | - 2.0 | | |
| Sharpest Curve without Superelevation (m) | 5,000 | 3,500 | 2,000 |

Table B-26 shows value of R and the resulting superelevation for each design speed.

**Table B-26 Superelevation related to design speed and horizontal curvature**

| Horizontal Curvature radius (m) | Superelevation (%) | | |
|---|---|---|---|
| | 100km/h | 80km/h | 60km/h |
| 5,000 - 4,000 | 2.0 | | |
| 4,000 - 3,000 | 3.0 | 2.0 | |
| 3,000 - 2,000 | 3.0 | 2.0 | |
| 2,000 - 1,500 | 4.0 | 3.0 | 2.0 |
| 1,500 - 1,250 | 4.0 | 3.0 | 2.0 |
| 1,250 - 1,000 | 5.0 | 4.0 | 3.0 |
| 1,000 - 900 | 5.0 | 4.0 | 3.0 |
| 900 - 800 | 5.0 | 4.0 | 3.0 |
| 800 - 700 | 6.0 | 5.0 | 3.0 |
| 700 - 600 | 6.0 | 5.0 | 4.0 |
| 600 - 500 | 6.0 | 5.0 | 4.0 |
| 500 - 400 | 6.0 | 6.0 | 5.0 |
| 400 - 300 | | 6.0 | 5.0 |
| 300 - 200 | | 6.0 | 6.0 |
| 200 - 150 | | | 6.0 |

(3) Minimum Transition Curve Length

Transition curves are desirable on high speed roads between circular curves of substantially different radii and between tangents and circular curves.

The length necessary for controlling the steering on a curve is calculated from the following formula, which provides required length for a natural and easy-to-follow path for drivers.

$$L = \frac{Vd}{3.6} \times t$$

where L : Minimum Transition Curve Length (m)

Vd : Design Speed (km/h)

t : Running Time through the Transition Curve (sec.)

Desirable running time through the curve to allow control of the steering is reported to be 3 to 5 seconds. The minimum transition curve length is set 50 m using the running time through the transition curve t = 3 sec and the design speed Vd = 100, 80 and 60 km/h.

To make the change of centrifugal acceleration tolerable, the rate of increase of centripetal acceleration (P $m/sec^3$) is examined by Short's equation where Pmax = 0.75 $m/sec^3$.

$$P = \frac{\left[\frac{Vd}{3.6}\right]^3}{L \times R}$$

where P : Rate of Increase of Centripetal Acceleration ($m/sec^3$)

Vd : Design Speed (km/h)

L : Minimum Transition Curve Length (m)

R : Minimum Curve Radius (m)

**Table B-27 Minimum Transition Curve Lengths and Its Rate of Acceleration**

| Design Speed (km/h) | 100 | 80 | 60 |
|---|---|---|---|
| Running Time (sec.) | 3 | | |
| Minimum Transition Curve Length (m) | 85 | 70 | 50 |
| Minimum Curve Radius (m) | 450 | 250 | 150 |
| Rate of Increase of Centripetal Acceleration ($m/sec^3$) | 0.55 < 0.75 | | |

(4) Minimum Horizontal Curve Length

The following values are designated to cover all the horizontal curve lengths, including transition curves if any, and to be of sufficient length for drivers to comfortably adjust their steering to allow for the change in curvature.

Rider Comfort (tolerable limit)

$L = 0.278 \times Vd \times t$

where L : Minimum Horizontal Curve Length (m)

Vd : Design Speed (km/h)

t : Minimum Required Steering Time on Curve (sec), t = 6 sec

**Table B-28 Minimum Horizontal Curve Length (tolerable limit)**

| Design Speed (km/h) | 100 | 80 | 60 |
|---|---|---|---|
| Min. Length Calculated (m) | 167 | 133 | 100 |
| Adopted Value (m) | 170 | 140 | 100 |

In the cases where the intersection angle ( $\theta$ ) is small, $7^\circ$ or less, it is desirable to use a longer horizontal curve length than the minimum value. Minimum horizontal curve length is calculated as follows:

Minimum Secant Length, $N_{min}$

$N_{min} = \theta_0 \times L / 6 = 0.020 \times L$

Where $\theta_0$: Intersection Angle to Govern Min. Secant Length, $\theta_0 = 7^\circ$ = 0.122 rad.

L : Minimum Transition Curve Length (m)

**Table B-29 Minimum Horizontal Curve Length ($N_{min}$)**

| Design Speed (km/h) | 100 | 80 | 60 |
|---|---|---|---|
| Min. Transition Curve Length (m) | 85 | 70 | 50 |
| Min. Secant Length (m) | 1.70 | 1.40 | 1.00 |

<u>Minimum Horizontal Curve Length, $L_{min}$</u>

$L_{min} = 12 \times N_{min} / \theta$ (rad.) $= 688 \times N_{min} / \theta$ (degree)

**Table B-30 Minimum Horizontal Curve Length (Nmin)**

| Design Speed (km/h) | 100 | 80 | 60 |
|---|---|---|---|
| Min. Secant Length (m) | 1.70 | 1.40 | 1.00 |
| Min. Curve Length (m) | 1,200/ $\theta$ | 1,000/ $\theta$ | 700/ $\theta$ |

(5) Minimum Radius of Curve not Required Transition Curve

The minimum radius of curve for which no transition curves are required is calculated by using the following formula:

$$R = \frac{1}{24} \times \frac{L^2}{S}$$

where S : Shift in Meters between Curve and Tangent (m)

L : Transition Curve Length (m)

R : Radius of Circular Curve (m)

Maximum shift $S_{max} = 0.20$ applied to the above formula and then minimum radius $R_{min}$ is calculated as follows:

**Table B-31 Minimum Radius of Curve not Required Transition Curve**

| Design Speed (km/h) | Min. Transition Curve Length (m) | Min. Radius (m) | |
|---|---|---|---|
| | | Calculated | Rounded |
| 100 | 85 | 1,505 | 1,500 |
| 80 | 70 | 1,020 | 1,000 |
| 60 | 50 | 520 | 500 |

(6) Superelevation Runoff

For added comfort and safety, the superelevation runoff should be effected uniformly over a length adequate for the design speed. In other words the length of superelevation runoff should exceed what is specified by the maximum relative slope mentioned below.

On the contrary, for the requirements of pavement drainage, the length of superelevation runoff in between –2 % and 2 % should not exceed what is computed by the minimum relative slope of 1/300.

$$Q = \frac{3.6 \times B \times W}{Vd}$$

where B : Traveled Way Width from Axle of Rotation (m)

W : Rolling Speed of Vehicle for Profiles (radian/sec.)

Q : Equivalent Maximum Relative Slopes for Profiles (m/m)

**Table B-32 Equivalent Maximum Relative Slopes for Profiles**

| Design Speed (km/h) | | 100 | 80 | 60 |
|---|---|---|---|---|
| B (m) | | 3.5 | | |
| W (rad. Sec.) | | 0.045 | 0.042 | 0.038 |
| Q | Calculated | 1:176 | 1:151 | 1:125 |
| | Adopted Value | 1:175 | 1:150 | 1:125 |

Note: The axle of rotation is located at the centerline.

(7) Grade

To establish design values for grades for which gradeability of trucks is the determining factor, data or assumption are needed for the following:

a) Size and power of a representative truck or truck combination to be used as a design vehicle along with the gradeability data for this vehicle.

A loaded truck, powered so that the mass/ power ratio is about 13 PS/t, is representative of the size and type of vehicle normally used for design control on main highway.

b) Minimum speed on the grade below which interference to following vehicles is considered unreasonable.

The effect of grades on truck speeds is much more pronounced than on speeds of passenger cars. Then, there is a general acceptance that driving speed for trucks on grade are allowed to the limit of half of design speed.

Under these assumptions, Minimum speed is expressed by these two factors, climbing power and resisting power, namely is calculated that the climbing power is equivalent or more than the resisting power by the following formula:

$$c \geqq r$$

where c : Climbing Power (kg/t)

r : Resisting Power (kg/t)

The climbing power for trucks is calculated by using the following formula:

$$c = \frac{270}{45} \times h \times 0.87 \times \{1.2 - 1.3(\frac{Va}{45} - 0.6)^2\}$$

where Va : Minimum Allowable Speed (km/h)

h : Horsepower (PS/t)

On the other hand, the resisting power for trucks is calculated by using the following formula:

$$r = 10 + 10 \times i + 0.0011 \times Va^2$$

where i : Grade (%)

Va : Minimum Allowable Speed (km/h)

Then maximum grade $i_{max}$ is calculated as follows:

**Table B-33 Maximum Grade**

| Design Speed (km/h) | | 100 | 80 | 60 |
|---|---|---|---|---|
| Minimum Allowable Speed (km/h) | | 50 | 40 | 30 |
| Q | Calculated | 4.57 | 6.23 | 7.01 |
| | Adopted Value | 4.0 | 6.0 | 7.0 |

(8) Minimum Vertical Curve Length

Vertical curves effect gradual change between tangent grades in crest and sag curves and should result in a design that is safe, comfortable in operation, pleasing in appearance and adequate for drainage.

The major control for safe operation on crest vertical curves is the provision of ample sight distance for the design speed and rider comfort, while headlight sight distance and rider comfort govern the length of sag vertical curve.

The following equations are used for the calculation of required vertical curve length and radius of vertical curve, of which longer length is applicable.

A. Rider Comfort (Tolerable Limit)

$$L = \frac{Vd}{3.6} \times t$$

where L : Vertical Curve Length (m)

Vd : Design Speed (km/h)

t : Minimum Required Time, t = 3 sec.

B. On Crest Curve (Object height: 0.2 m, Eye Height: 1.2 m)

$$L = \frac{D^2 \times i}{476} \quad \text{OR} \quad R = \frac{100 \times D^2}{476}$$

where L : Vertical Curve Length (m)

D : Sight Distance (m)

R : Radius of Vertical Curve (m)

i : Algebraic Difference in Grade (%)

As discussed previously, the each design speed is recommended to the Eastern Arterial Road. However, the following comparison may ascertain its justification.

**Table B-34 Minimum Vertical Curve Radius on Crest Curve**

| Design Speed (km/h) | Sight Distance (m) | On Crest Curve (m) | |
|---|---|---|---|
| | | Min. Vertical Curve Length | Min. Radius |
| 100 | 205 | 710 | 8,850 |
| 80 | 140 | 500 | 4,150 |
| 60 | 85 | 215 | 1,550 |

Note: The computation is made on the condition that the algebraic difference of maximum grades.

C. On Sag Curve

(Headlight Sight Distance: Headlight Height = 0.75m, Angle = 1°)

$$L = \frac{D^2 \times i}{150 + 3.5 \times D} \quad \text{OR} \quad R = \frac{100 \times D^2}{150 + 3.5 \times D}$$

where L : Vertical Curve Length (m)

D : Sight Distance (m)

R : Radius of Vertical Curve (m)

i : Algebraic Difference in Grade (%)

**Table B-35 Minimum Vertical Curve Radius on Sag Curve**

| Design Speed (km/h) | Sight Distance (m) | On Crest Curve (m) | |
|---|---|---|---|
| | | Min. Vertical Curve Length | Min. Radius |
| 100 | 205 | 390 | 4,845 |
| 80 | 140 | 370 | 3,065 |
| 60 | 85 | 230 | 1,615 |

Note: The computation is made on the condition that the algebraic difference of maximum grades.

## Table B-36 Minimum Vertical Curve Length

Design Speed 100 km/h
Sight Distance 205 m

| Algebraic Difference in Grade (%) | On Crest Curve | | | On Sag Curve | | |
|---|---|---|---|---|---|---|
| | Rider Comfort | Sight Distance | Adopt Value | Rider Comfort | Sight Distance | Adopt Value |
| 8.0 | 83 | 706 | 706 | 83 | 388 | 388 |
| 7.5 | 83 | 662 | 662 | 83 | 363 | 363 |
| 7.0 | 83 | 618 | 618 | 83 | 339 | 339 |
| 6.5 | 83 | 574 | 574 | 83 | 315 | 315 |
| 6.0 | 83 | 530 | 530 | 83 | 291 | 291 |
| 5.5 | 83 | 486 | 486 | 83 | 266 | 266 |
| 5.0 | 83 | 441 | 441 | 83 | 242 | 242 |
| 4.5 | 83 | 397 | 397 | 83 | 218 | 218 |
| 4.0 | 83 | 353 | 353 | 83 | 194 | 194 |
| 3.5 | 83 | 309 | 309 | 83 | 170 | 170 |
| 3.0 | 83 | 265 | 265 | 83 | 145 | 145 |
| 2.5 | 83 | 221 | 221 | 83 | 121 | 121 |
| 2.0 | 83 | 177 | 177 | 83 | 97 | 97 |
| 1.5 | 83 | 132 | 132 | 83 | 73 | 83 |
| 1.0 | 83 | 88 | 88 | 83 | 48 | 83 |
| 0.5 | 83 | 44 | 83 | 83 | 24 | 83 |

Design Speed 80 km/h
Sight Distance 140 m

| Algebraic Difference in Grade (%) | On Crest Curve | | | On Sag Curve | | |
|---|---|---|---|---|---|---|
| | Rider Comfort | Sight Distance | Adopt Value | Rider Comfort | Sight Distance | Adopt Value |
| 12.0 | 67 | 494 | 494 | 67 | 368 | 368 |
| 11.5 | 67 | 474 | 474 | 67 | 352 | 352 |
| 11.0 | 67 | 453 | 453 | 67 | 337 | 337 |
| 10.5 | 67 | 432 | 432 | 67 | 322 | 322 |
| 10.0 | 67 | 412 | 412 | 67 | 306 | 306 |
| 9.5 | 67 | 391 | 391 | 67 | 291 | 291 |
| 9.0 | 67 | 371 | 371 | 67 | 276 | 276 |
| 8.5 | 67 | 350 | 350 | 67 | 260 | 260 |
| 8.0 | 67 | 329 | 329 | 67 | 245 | 245 |
| 7.5 | 67 | 309 | 309 | 67 | 230 | 230 |
| 7.0 | 67 | 288 | 288 | 67 | 214 | 214 |
| 6.5 | 67 | 268 | 268 | 67 | 199 | 199 |
| 6.0 | 67 | 247 | 247 | 67 | 184 | 184 |
| 5.5 | 67 | 226 | 226 | 67 | 168 | 168 |
| 5.0 | 67 | 206 | 206 | 67 | 153 | 153 |
| 4.5 | 67 | 185 | 185 | 67 | 138 | 138 |
| 4.0 | 67 | 165 | 165 | 67 | 123 | 123 |
| 3.5 | 67 | 144 | 144 | 67 | 107 | 107 |
| 3.0 | 67 | 124 | 124 | 67 | 92 | 92 |
| 2.5 | 67 | 103 | 103 | 67 | 77 | 77 |
| 2.0 | 67 | 82 | 82 | 67 | 61 | 67 |
| 1.5 | 67 | 62 | 67 | 67 | 46 | 67 |
| 1.0 | 67 | 41 | 67 | 67 | 31 | 67 |
| 0.5 | 67 | 21 | 67 | 67 | 15 | 67 |

Design Speed 60 km/h
Sight Distance 85 m

| Algebraic Difference in Grade (%) | On Crest Curve | | | On Sag Curve | | |
|---|---|---|---|---|---|---|
| | Rider Comfort | Sight Distance | Adopt Value | Rider Comfort | Sight Distance | Adopt Value |
| 14.0 | 50 | 213 | 213 | 50 | 226 | 226 |
| 13.5 | 50 | 205 | 205 | 50 | 218 | 218 |
| 13.0 | 50 | 197 | 197 | 50 | 210 | 210 |
| 12.5 | 50 | 190 | 190 | 50 | 202 | 202 |
| 12.0 | 50 | 182 | 182 | 50 | 194 | 194 |
| 11.5 | 50 | 175 | 175 | 50 | 186 | 186 |
| 11.0 | 50 | 167 | 167 | 50 | 178 | 178 |
| 10.5 | 50 | 159 | 159 | 50 | 170 | 170 |
| 10.0 | 50 | 152 | 152 | 50 | 161 | 161 |
| 9.5 | 50 | 144 | 144 | 50 | 153 | 153 |
| 9.0 | 50 | 137 | 137 | 50 | 145 | 145 |
| 8.5 | 50 | 129 | 129 | 50 | 137 | 137 |
| 8.0 | 50 | 121 | 121 | 50 | 129 | 129 |
| 7.5 | 50 | 114 | 114 | 50 | 121 | 121 |
| 7.0 | 50 | 106 | 106 | 50 | 113 | 113 |
| 6.5 | 50 | 99 | 99 | 50 | 105 | 105 |
| 6.0 | 50 | 91 | 91 | 50 | 97 | 97 |
| 5.5 | 50 | 83 | 83 | 50 | 89 | 89 |
| 5.0 | 50 | 76 | 76 | 50 | 81 | 81 |
| 4.5 | 50 | 68 | 68 | 50 | 73 | 73 |
| 4.0 | 50 | 61 | 61 | 50 | 65 | 65 |
| 3.5 | 50 | 53 | 53 | 50 | 57 | 57 |
| 3.0 | 50 | 46 | 50 | 50 | 48 | 50 |
| 2.5 | 50 | 38 | 50 | 50 | 40 | 50 |
| 2.0 | 50 | 30 | 50 | 50 | 32 | 50 |
| 1.5 | 50 | 23 | 50 | 50 | 24 | 50 |
| 1.0 | 50 | 15 | 50 | 50 | 16 | 50 |
| 0.5 | 50 | 8 | 50 | 50 | 8 | 50 |

## B-4. Pavement Design & Overlay
## AASHTO Pavement Design & Overlay

**$\log_{10}W_{18}=Z_R*S_0+9.36*\log_{10}(SN+1)-0.20+\log_{10}(\Delta PSI/(4.2-1.5))/((0.40+1094/(SN+1)^{5.19})+2.32*\log_{10}M_R-8.07$**

*Effective Resilient Modulus of Subgrade (psi) $M_R=$ 1,500*CBR

*Reliability: 90% (middle range of Local Area) $Z_R=$ -1.282

*Standard Deviation: 0.35

*Initial Pavement Serviceability Index for the Asphalt Pavement: 4.2

*Terminal Serviceability Index: 2.5

*ΔPSI = 4.2 - 2.5 = 1.7

*Cumulative traffic (ESAL)

**Baganuur-Jargartkhaan:** 32,300 * ((1+g) t-1) / g g = 8.3 %

**Jargartkhaan-Undurkhaan:** 25,300 * ((1+g) t-1) / g g = 8.1 %

### 1. Baganuur-Jargartkhaan:

Asphalt Pavement ESAL for **7 years**: $32{,}300*((1.083)^{12}-1)/0.083 - 32{,}300*((1.083)^{5}-1)/0.083=$ 433,300

**Input Data for SN**

| $W_{18}$ | $Z_R$ | $S_0$ | ΔPSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **8** | 12,000 | | | | 4.079 |
| 4.33E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | 5.637 | -0.449 | -0.201 | 4.176 |
| | | | | **12** | 18,000 | | | | 4.255 |

**$Y=Z_R*S_0+9.36*\log_{10}(SN+1)-0.20+\log_{10}(\Delta PSI/(4.2-1.5))/((0.40+1094/(SN+1)^{5.19})+2.32*\log_{10}M_R-8.07$**

**Computed SN**

| **CBR=8** | | **CBR=10** | | **CBR=12** | | |
|---|---|---|---|---|---|---|
| $SN_0$ | Y | SN | Y | SN | Y | $\log_{10}W_{18}$ |
| 2.40 | 5.633 | 2.20 | 5.631 | 2.04 | 5.621 | |
| **2.41** | 5.643 | **2.21** | 5.643 | **2.05** | 5.633 | **5.637** |
| 2.42 | 5.654 | 2.22 | 5.655 | 2.06 | 5.646 | |

| Pavement Layer | a | **CBR=8** | | **CBR=10** | | **CBR=12** | |
|---|---|---|---|---|---|---|---|
| | | Thickness (D) | SN | Thickness (D) | SN | Thickness (D) | SN |
| Asphalt Concrete Surface | 0.45 | 2.0 | 0.90 | 2.0 | 0.90 | 2.0 | 0.90 |
| Granular Base Course (CBR>80) | 0.14 | 6.0 | 0.84 | 5.9 | 0.83 | 5.0 | 0.70 |
| Granular Subbase(20<CBR<30) | 0.08 | 8.5 | 0.68 | 6.0 | 0.48 | 5.6 | 0.45 |
| Total | - | **16.5** | 2.42 | **13.9** | 2.21 | **12.6** | 2.05 |

Asphalt Concrete Overlay (1)

**$SN_{OL} = SN_Y - F_{RL} \times SNeff$**

Where,

**$SN_{OL}$** : Required Overlay Structure Number

**$SN_f$** : Structure Nember required for future traffic

**$F_{RL}$** : Remaining Life Percentage

**SNeff** : Effective Structure Number of Exixting Pavement

$\Delta PSI_{TR}$ = ΔPSI (loss of Serviceability)

= 1.7

Cumulative ESALs for between 7 to 14 years is as follow.

**ESAL** = 1,190,500 - 433,300 = 7.57E+05

**Input Data for $SN_f$** **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 7.57E+05 | -1.282 | 0.35 | 1.7 | **8** | 12,000 | **5.879** | -0.449 | -0.201 | 4.079 |
| | | | | **10** | 15,000 | | | | 4.176 |
| | | | | **12** | 18,000 | | | | 4.255 |

**Computed $SN_f$**

| CBR = 8 | | | CBR = 10 | | | CBR = 12 | | |
|---|---|---|---|---|---|---|---|---|
| **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y |
| 2.41 | 2.62 | 5.862 | 2.21 | 2.41 | 5.868 | 2.05 | 2.24 | 5.862 |
| **$R_{LX}$** | **2.63** | **5.871** | **$R_{LX}$** | **2.42** | **5.879** | **$R_{LX}$** | **2.25** | **5.873** |
| - | 2.64 | 5.881 | - | 2.43 | 5.890 | - | 2.26 | 5.885 |

| $W_{18}$(N) | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 7.57E+05 | -1.282 | 0.35 | **2.2** | 8 | 12,000 | 5.879 | -0.449 | -0.089 | 4.079 |
| | | | | 10 | 15,000 | | | | 4.176 |
| | | | | 12 | 18,000 | | | | 4.255 |

| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = SNf - $F_{RL}$ * Sneff |
|---|---|---|---|---|---|---|---|---|
| **8** | **2.63** | **5.935** | **8.61E+05** | 12.1% | 0.80 | **0.960** | 2.314 | 0.779 |
| **10** | **2.42** | **5.929** | **8.49E+05** | 10.8% | 0.80 | **0.950** | 2.100 | 0.740 |
| **12** | **2.25** | **5.913** | **8.19E+05** | 7.5% | 0.80 | **0.950** | 1.948 | 0.872 |

| CBR | $D_{OL}$=$SN_{OL}$ / al | |
|---|---|---|
| **8** | 1.73 in | 4.4 cm |
| **10** | 1.65 in | 4.2 cm |
| **12** | 1.94 in | 4.9 cm |

Asphalt Overlay (2)

Cumulative ESALs for between 14 to 20 years is as follow.

**ESAL** = 2,276,700 - 1,190,500 = 1.09E+06

**Input Data for $SN_f$** **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 1.09E+06 | -1.282 | 0.35 | 1.7 | **8** | 12,000 | **6.036** | -0.449 | -0.201 | 4.079 |
| | | | | **10** | 15,000 | | | | 4.176 |
| | | | | **12** | 18,000 | | | | 4.255 |

**Computed $SN_f$**

| CBR = 8 | | | CBR = 10 | | | CBR = 12 | | |
|---|---|---|---|---|---|---|---|---|
| **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y |
| 2.63 | 2.79 | 6.026 | 2.42 | 2.56 | 6.026 | 2.25 | 2.39 | 6.030 |
| **$R_{LX}$** | **2.80** | **6.035** | **$R_{LX}$** | **2.57** | **6.036** | **$R_{LX}$** | **2.40** | **6.041** |
| - | 2.81 | 6.045 | - | 2.58 | 6.046 | - | 2.41 | 6.052 |

| $W_{18}$(N) | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 1.09E+06 | -1.282 | 0.35 | **2.2** | 8 | 12,000 | 6.036 | -0.449 | -0.089 | 4.079 |
| | | | | 10 | 15,000 | | | | 4.176 |
| | | | | 12 | 18,000 | | | | 4.255 |

| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = SNf - $F_{RL}$ * Sneff |
|---|---|---|---|---|---|---|---|---|
| **8** | **2.80** | **6.111** | **1.29E+06** | 15.9% | 0.80 | **0.960** | 2.525 | 0.780 |
| **10** | **2.57** | **6.096** | **1.25E+06** | 12.8% | 0.80 | **0.950** | 2.299 | 0.731 |
| **12** | **2.40** | **6.090** | **1.23E+06** | 11.6% | 0.80 | **0.950** | 2.138 | 0.870 |

| CBR | $D_{OL}$=$SN_{OL}$ / al | |
|---|---|---|
| **8** | 1.73 in | 4.4 cm |
| **10** | 1.62 in | 4.1 cm |
| **12** | 1.93 in | 4.9 cm |

## AASHTO Pavement Design & Overlay

$$\log_{10}W_{18}=Z_R*S_0+9.36*\log_{10}(SN+1)-0.20+\log_{10}(\Delta PSI/(4.2-1.5))/((0.40+1094/(SN+1)^{5.19})+2.32*\log_{10}M_R-8.07$$

| | | |
|---|---|---|
| *Effective Resilient Modulus of Subgrade (psi) | $M_R$= | 1,500*CBR |
| *Reliability: 90% (middle range of Local Area) | $Z_R$ = | -1.282 |
| *Standard Deviation: | | 0.35 |
| *Initial Pavement Serviceability Index for the Asphalt Pavement: | | 4.2 |
| *Terminal Serviceability Index: | | 2.5 |
| *Δ PSI = 4.2 − 2.5 = | | 1.7 |

*Cumulative traffic (ESAL)

**Baganuur-Jargartkhaan**: 32,300 * ((1+g) t-1) / g    g = 8.3 %
**Jargartkhaan-Undurkhaan**: 25,300 * ((1+g) t-1) / g    g = 8.1 %

## 2. Jargartkhaan - Undrukhaan:

Asphalt Pavement    ESAL for **7 years**: $25{,}300*((1.081)^{12}-1) / 0.081 - 25{,}300*((1.081)^{5}-1) / 0.081=$    334,200

**Input Data for SN**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}$( Δ PSI /(4.2-1.5)) | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 3.34E+05 | -1.282 | 0.35 | 1.7 | **8** | 12,000 | 5.524 | -0.449 | -0.201 | 4.079 |
| | | | | **10** | 15,000 | | | | 4.176 |
| | | | | **12** | 18,000 | | | | 4.255 |

$$Y=Z_R*S_0+9.36*\log_{10}(SN+1)-0.20+\log_{10}(\Delta PSI/(4.2-1.5))/((0.40+1094/(SN+1)^{5.19})+2.32*\log_{10}M_R-8.07$$

**Computed SN**

| **CBR=8** | | **CBR=10** | | **CBR=12** | | |
|---|---|---|---|---|---|---|
| $SN_0$ | Y | SN | Y | SN | Y | $\log_{10}W_{18}$ |
| 2.29 | 5.511 | 2.10 | 5.511 | 1.96 | 5.518 | **5.524** |
| 2.30 | 5.522 | 2.11 | 5.524 | 1.97 | 5.531 | |
| 2.31 | 5.533 | 2.12 | 5.536 | 1.98 | 5.544 | |

| Pavement Layer | a | **CBR=8** | | **CBR=10** | | **CBR=12** | |
|---|---|---|---|---|---|---|---|
| | | Thickness (D) | SN | Thickness (D) | SN | Thickness (D) | SN |
| Asphalt Concrete Surface | 0.45 | 2.0 | 0.90 | 2.0 | 0.90 | 2.0 | 0.90 |
| Granular Base Course (CBR>80) | 0.14 | 6.0 | 0.84 | 5.0 | 0.70 | 4.8 | 0.67 |
| Granular Subbase(20<CBR<30) | 0.08 | 7.0 | 0.56 | 6.4 | 0.51 | 5.0 | 0.40 |
| Total | - | **15.0** | 2.30 | **13.4** | 2.11 | **11.8** | 1.97 |

Asphalt Concrete Overlay (1)

$$SN_{OL} = SN_Y - F_{RL} \times SNeff$$

Where,

| | | |
|---|---|---|
| $SN_{OL}$ | : | Required Overlay Structure Number |
| $SN_f$ | : | Structure Nember required for future traffic |
| $F_{RL}$ | : | Remaining Life Percentage |
| SNeff | : | Effective Structure Number of Exixting Pavement |

$\Delta PSI_{TR}$ = ΔPSI (loss of Serviceability)
= 1.7

Cumulative ESALs for between 7 to 14 years is as follow.

**ESAL** = 910,800 - 334,200 = 5.77E+05

**Input Data for $SN_f$** **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | ΔPSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 5.77E+05 | -1.282 | 0.35 | 1.7 | **8** | 12,000 | 5.761 | -0.449 | -0.201 | 4.079 |
| | | | | **10** | 15,000 | | | | 4.176 |
| | | | | **12** | 18,000 | | | | 4.255 |

**Computed $SN_f$**

| CBR = 8 | | | CBR = 10 | | | CBR = 12 | | |
|---|---|---|---|---|---|---|---|---|
| **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y |
| 2.30 | 2.51 | 5.749 | 2.11 | 2.30 | 5.747 | 1.97 | 2.14 | 5.744 |
| **$R_{LX}$** | **2.52** | **5.760** | **$R_{LX}$** | **2.31** | **5.758** | **$R_{LX}$** | **2.15** | 5.756 |
| - | 2.53 | 5.770 | - | 2.32 | 5.769 | - | 2.16 | 5.768 |

| $W_{18}$ (N) | $Z_R$ | $S_0$ | ΔPSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 5.77E+05 | -1.282 | 0.35 | 2.2 | 8 | 12,000 | 5.761 | -0.449 | -0.089 | 4.079 |
| | | | | 10 | 15,000 | | | | 4.176 |
| | | | | 12 | 18,000 | | | | 4.255 |

| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = SNf - $F_{RL}$ * Sneff |
|---|---|---|---|---|---|---|---|---|
| **8** | **2.52** | **5.816** | **6.55E+05** | 11.9% | 0.80 | 0.960 | 2.208 | 0.754 |
| **10** | **2.31** | **5.801** | **6.33E+05** | 8.9% | 0.80 | 0.950 | 2.005 | 0.706 |
| **12** | **2.15** | **5.790** | **6.17E+05** | 6.5% | 0.80 | 0.940 | 1.852 | 0.839 |

| CBR | $D_{OL}$=$SN_{OL}$ / al | |
|---|---|---|
| **8** | 1.67 in | 4.3 cm |
| **10** | 1.57 in | 4.0 cm |
| **12** | 1.86 in | 4.7 cm |

Overlay (2)

Cumulative ESALs for between 14 to 20 years is as follow.

**ESAL** = 1,728,000 - 910,800 = 8.17E+05

**Input Data for $SN_f$** **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | ΔPSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 8.17E+05 | -1.282 | 0.35 | 1.7 | **8** | 12,000 | 5.912 | -0.449 | -0.201 | 4.079 |
| | | | | **10** | 15,000 | | | | 4.176 |
| | | | | **12** | 18,000 | | | | 4.255 |

**Computed $SN_f$**

| CBR = 8 | | | CBR = 10 | | | CBR = 12 | | |
|---|---|---|---|---|---|---|---|---|
| **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y | **$SN_0$** | **$SN_f$** | Y |
| 2.52 | 2.66 | 5.901 | 2.31 | 2.44 | 5.901 | 2.15 | 2.28 | 5.908 |
| **$R_{LX}$** | **2.67** | **5.911** | **$R_{LX}$** | **2.45** | **5.911** | **$R_{LX}$** | **2.29** | **5.919** |
| - | 2.68 | 5.921 | - | 2.46 | 5.922 | - | 2.30 | 5.930 |

| $W_{18}$ (N) | $Z_R$ | $S_0$ | ΔPSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 8.17E+05 | -1.282 | 0.35 | 2.2 | 8 | 12,000 | 5.912 | -0.449 | -0.089 | 4.079 |
| | | | | 10 | 15,000 | | | | 4.176 |
| | | | | 12 | 18,000 | | | | 4.255 |

| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = SNf - $F_{RL}$ * Sneff |
|---|---|---|---|---|---|---|---|---|
| **8** | **2.67** | **5.977** | **9.49E+05** | 13.9% | 0.80 | 0.960 | 2.419 | 0.735 |
| **10** | **2.45** | **5.963** | **9.18E+05** | 11.0% | 0.80 | 0.950 | 2.195 | 0.694 |
| **12** | **2.29** | **5.961** | **9.14E+05** | 10.6% | 0.80 | 0.940 | 2.021 | 0.843 |

| CBR | $D_{OL}$=$SN_{OL}$ / al | |
|---|---|---|
| **8** | 1.63 in | 4.1 cm |
| **10** | 1.54 in | 3.9 cm |
| **12** | 1.87 in | 4.8 cm |

## Asphalt Concrete Overlay  Baganuur Existing Pavement Section

$SN_{OL} = SN_Y - F_{RL} \times SNeff$

| | | | |
|---|---|---|---|
| Where, | $SN_{OL}$ | : | Required Overlay Structure Number |
| | $SN_f$ | : | Structure Number required for future traffic |
| | $F_{RL}$ | : | Remaining Life Percentage |
| | SNeff | : | Effective Structure Number of Exixting Pavement |
| | $\Delta PSI_{TR}$ | = | ΔPSI (loss of Serviceability) |
| | | = | 1.7 |

**Case 1:** Asphalt Surface  Cumulative ESALs for between 2005 to 2012 years is as follow.

**ESAL =** 751,376 - 252,038 = 4.99E+05

**Input Data for $SN_f$**  **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 4.99E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | **5.698** | -0.449 | -0.201 | 4.176 |

**Computed $SN_f$**

| CBR = 10 | | |
|---|---|---|
| $SN_0$ | $SN_f$ | Y |
| 2.04 | 2.25 | 5.690 |
| $R_{LX}$ | 2.26 | 5.701 |
| - | 2.27 | 5.713 |

| $SN_0$ | | | |
|---|---|---|---|
| | Asphalt Surface: | 4.72 in x 0.45 / 4 = | 0.53 |
| | Base Course: | 7.87 in x 0.10 = | 0.79 |
| | Subbase | 12 in x 0.06 = | 0.72 |
| | | | 2.04 |

| $W_{18}$(N) | | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.99E+05 | | -1.282 | 0.35 | **2.2** | 10 | 15,000 | 5.698 | -0.449 | -0.089 | | 4.176 |
| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = SNf - $F_{RL}$ * Sneff | $D_{OL}$=$SN_{OL}$ / al | |
| **10** | **2.26** | **5.741** | **5.51E+05** | 9.4% | | 0.80 | **0.870** | 1.773 | 0.842 | 1.87 in | 4.8 cm |

**Case 2:** Bituminous Surface Treatment  Cumulative ESALs for between 2005 to 2012 years is as follow.

**ESAL =** 751,376 - 252,038 = 4.99E+05

**Input Data for $SN_f$**  **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 4.99E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | **5.698** | -0.449 | -0.201 | 4.176 |

**Computed $SN_f$**

| CBR = 10 | | |
|---|---|---|
| $SN_0$ | $SN_f$ | Y |
| 1.66 | 2.25 | 5.690 |
| $R_{LX}$ | 2.26 | 5.701 |
| - | 2.27 | 5.713 |

| $SN_0$ | | | |
|---|---|---|---|
| | Bituminous Surface: | 2.76 in x 0.3 /3 = | 0.28 |
| | Base Course: | 7.87 in x 0.10 = | 0.79 |
| | Subbase | 10 in x 0.06 = | 0.60 |
| | | | 1.66 |

| $W_{18}$(N) | | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.99E+05 | | -1.282 | 0.35 | **2.2** | 10 | 15,000 | 5.698 | -0.449 | -0.089 | | 4.176 |
| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = SNf - $F_{RL}$ * Sneff | $D_{OL}$=$SN_{OL}$ / al | |
| **10** | **2.26** | **5.741** | **5.51E+05** | 9.4% | | 0.80 | **0.910** | 1.513 | 1.049 | 2.33 in | 5.9 cm |

## Asphalt Concrete Overlay    Baganuur Existing Pavement Section

$SN_{OL} = SN_Y - F_{RL} \times SNeff$

Where,

| | | |
|---|---|---|
| $SN_{OL}$ | : | Required Overlay Structure Number |
| $SN_f$ | : | Structure Number required for future traffic |
| $F_{RL}$ | : | Remaining Life Percentage |
| SNeff | : | Effective Structure Number of Exixting Pavement |
| $\Delta PSI_{TR}$ | = | ΔPSI (loss of Serviceability) |
| | = | 1.7 |

**Case 1:** Asphalt Surface    Cumulative ESALs for between 2012 to 2019 years is as follow.

**ESAL =** 1,497,250 - 751,376 = 7.46E+05

**Input Data for $SN_f$**    **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 7.46E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | 5.873 | -0.449 | -0.201 | 4.176 |

**Computed $SN_f$**

| CBR = 10 | | |
|---|---|---|
| $SN_0$ | $SN_f$ | Y |
| 2.15 | 2.41 | 5.868 |
| $R_{LX}$ | 2.42 | 5.879 |
| - | 2.43 | 5.890 |

| $SN_0$ | | | |
|---|---|---|---|
| | Asphalt Surface: | 1.89 in x 0.45 / 2 = | 0.43 |
| | Base Course: | 12.5 in x 0.09 = | 1.00 |
| | Subbase | 12 in x 0.06 = | 0.72 |
| | | | 2.15 |

| $W_{18}$(N) | | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7.46E+05 | | -1.282 | 0.35 | **2.2** | 10 | 15,000 | 5.873 | -0.449 | -0.089 | | 4.176 |
| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = $SN_f$ - $F_{RL}$ * Sneff | $D_{OL}$=$SN_{OL}$ / al | |
| **10** | **2.42** | **5.929** | **8.49E+05** | 12.1% | | 0.80 | **0.910** | 1.952 | 0.858 | 1.91 in | 4.8 cm |

**Case 2:** Bituminous Surface Treatment    Cumulative ESALs for between 2012 to 2019 years is as follow.

**ESAL =** 1,497,250 - 751,376 = 7.46E+05

**Input Data for $SN_f$**    **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 7.46E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | **5.873** | -0.449 | -0.201 | 4.176 |

**Computed $SN_f$**

| CBR = 10 | | |
|---|---|---|
| $SN_0$ | $SN_f$ | Y |
| 2.07 | 2.41 | 5.868 |
| $R_{LX}$ | **2.42** | **5.879** |
| - | 2.43 | 5.890 |

| $SN_0$ | | | |
|---|---|---|---|
| | Bituminous Surface: | 2.28 in x 0.45 /2 = | 0.51 |
| | Base Course: | 10.6 in x 0.09 = | 0.95 |
| | Subbase | 10 in x 0.06 = | 0.60 |
| | | | 2.07 |

| $W_{18}$(N) | | $Z_R$ | $S_0$ | Δ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R$*$S_0$ | $\log_{10}$( Δ PSI/(4.2-1.5)) | | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7.46E+05 | | -1.282 | 0.35 | **2.2** | 10 | 15,000 | 5.873 | -0.449 | -0.089 | | 4.176 |
| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X$ * $SN_0$ | $SN_{OL}$ = $SN_f$ - $F_{RL}$ * Sneff | $D_{OL}$=$SN_{OL}$ / al | |
| **10** | **2.42** | **5.929** | **8.49E+05** | 12.1% | | 0.80 | **0.900** | 1.860 | 0.932 | 2.07 in | 5.3 cm |

## Asphalt Concrete Overlay — Baganuur Existing Pavement Section

$$SN_{OL} = SN_Y - F_{RL} \times SNeff$$

Where,

| | | |
|---|---|---|
| $SN_{OL}$ | : | Required Overlay Structure Number |
| $SN_f$ | : | Structure Nember required for future traffic |
| $F_{RL}$ | : | Remaining Life Percentage |
| SNeff | : | Effective Structure Number of Exixting Pavement |
| $\Delta PSI_{TR}$ | = | $\Delta PSI$ (loss of Serviceability) |
| | = | 1.7 |

**Case 1:** Asphalt Surface — Cumulative ESALs for between 2019 to 2025 years is as follow.

**ESAL =** 2,423,593 - 1,497,250 = 9.26E+05

**Input Data for $SN_f$** — **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | $\Delta$ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 9.26E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | 5.967 | -0.449 | -0.201 | 4.176 |

**Computed $SN_f$**

| CBR = 10 | | |
|---|---|---|
| $SN_0$ | $SN_f$ | Y |
| 2.15 | 2.49 | 5.953 |
| $R_{LX}$ | **2.50** | 5.964 |
| - | 2.51 | 5.974 |

| $SN_0$ | | | |
|---|---|---|---|
| | Asphalt Surface: | 1.89 in x 0.45 / 2 = | 0.43 |
| | Base Course: | 14.5 in x 0.09 = | 1.00 |
| | Subbase | 12 in x 0.06 = | 0.72 |
| | | | 2.15 |

| $W_{18}$ (N) | $Z_R$ | $S_0$ | $\Delta$ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 9.26E+05 | -1.282 | 0.35 | **2.2** | 10 | 15,000 | 5.967 | -0.449 | -0.089 | 4.176 |

| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X * SN_0$ | $SN_{OL} = SNf - F_{RL} * Sneff$ | $D_{OL}=SN_{OL}$ / al | |
|---|---|---|---|---|---|---|---|---|---|---|
| **10** | **2.50** | **6.019** | **1.04E+06** | 11.3% | 0.80 | **0.910** | 1.952 | 0.938 | 2.09 in | 5.3 cm |

**Case 2:** Bituminous Surface Treatment — Cumulative ESALs for between 2019 to 2025 years is as follow.

**ESAL =** 2,423,593 - 1,497,250 = 9.26E+05

**Input Data for $SN_f$** — **Terminal Serviceability Index = 2.50**

| $W_{18}$ | $Z_R$ | $S_0$ | $\Delta$ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 9.26E+05 | -1.282 | 0.35 | 1.7 | **10** | 15,000 | 5.967 | -0.449 | -0.201 | 4.176 |

**Computed $SN_f$**

| CBR = 10 | | |
|---|---|---|
| $SN_0$ | $SN_f$ | Y |
| 2.36 | 2.49 | 5.953 |
| $R_{LX}$ | **2.50** | 5.964 |
| - | 2.51 | 5.974 |

| $SN_0$ | | | |
|---|---|---|---|
| | Bituminous Surface: | 2.08 in x 0.45 /2 = | 0.47 |
| | Base Course: | 14.4 in x 0.09 = | 1.30 |
| | Subbase | 10 in x 0.06 = | 0.60 |
| | | | 2.36 |

| $W_{18}$ (N) | $Z_R$ | $S_0$ | $\Delta$ PSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 9.26E+05 | -1.282 | 0.35 | **2.2** | 10 | 15,000 | 5.967 | -0.449 | -0.089 | 4.176 |

| CBR | $SN_f$ | Y | $W_{18}$ ($N_{fy}$) | $R_{LY}$ = ( Nfy - N ) / Nfy | $F_{RL}$ | $C_X$ by estimate | Sneff = $C_X * SN_0$ | $SN_{OL} = SNf - F_{RL} * Sneff$ | $D_{OL}=SN_{OL}$ / al | |
|---|---|---|---|---|---|---|---|---|---|---|
| **10** | **2.50** | **6.019** | **1.04E+06** | 11.3% | 0.80 | **0.910** | **2.151** | 0.779 | 1.73 in | 4.4 cm |

**Evaluation of Erdene - Baganuur pavement**

Assuming pavement structure is as follow based on design report.

| Pavement Structure: | | | | |
|---|---|---|---|---|
| | Asphalt concrete surface | 6 cm | = | 2.36 in |
| | | SN1 | = | 1.06 |
| | Base Course | 15 cm | = | 5.91 in |
| | | SN2 | = | 0.59 |
| | Road bed | 30 cm | = | 11.81 in |
| | | SN3 | = | 0.94 |
| | | SN | = | 2.60 |

On the other hand, computed pavement structure is as follows.

$$\log_{10}W_{18}=Z_R*S_0+9.36*\log_{10}(SN+1)-0.20+\log_{10}(\Delta PSI/(4.2-1.5))/((0.40+1094/(SN+1)^{5.19})+2.32*\log_{10}M_R-8.07$$

*Effective Resilient Modulus of Subgrade (psi) $M_R$= 1,500*CBR

*Reliability: 90% (middle range of Local Area) $Z_R$ = -1.282

*Standard Deviation: 0.35

*Initial Pavement Serviceability Index for the Asphalt Pavement: 4.2

*Terminal Serviceability Index: 2.5

*ΔPSI = 4.2 - 2.5 = 1.7

*Cumulative traffic (ESAL) **Erdene-Baganuur:** 44,800 * ((1+g) t-1) / g g = 5.9 %

ESAL for **10 years**: $44,800*((1.059)^{13}-1) / 0.059 - 44,800*((1.059)^{3}-1) / 0.059=$ 698,000

**Input Data for SN**

| $W_{18}$ | $Z_R$ | $S_0$ | ΔPSI | CBR | $M_R$ | $\log_{10}W_{18}$ | $Z_R*S_0$ | $\log_{10}(\Delta PSI/(4.2-1.5))$ | $\log_{10}M_R$ |
|---|---|---|---|---|---|---|---|---|---|
| 6.98E 05 | -1.282 | 0.35 | 1.7 | 8 | 12,000 | 5.844 | -0.449 | -0.201 | 4.079 |

$$Y=Z_R*S_0+9.36*\log_{10}(SN+1)-0.20+\log_{10}(\Delta PSI/(4.2-1.5))/((0.40+1094/(SN+1)^{5.19})+2.32*\log_{10}M_R-8.07$$

**Computed SN**

| CBR = 8 | | |
|---|---|---|
| $SN_0$ | Y | $\log_{10}W_{18}$ |
| 2.59 | 5.831 | |
| 2.60 | 5.842 | **5.844** |
| 2.61 | 5.852 | |

| Pavement Layer | a | CBR =8 | |
|---|---|---|---|
| | | Thickness (D) | SN |
| Asphalt Concrete Surface | 0.45 | 2.36 | 1.06 |
| Granular Base Course (CBR>30) | 0.10 | 7.87 | 0.79 |
| Road bed (10<CBR<20) | 0.06 | 12.50 | 0.75 |
| Total | - | **22.73** | 2.60 |

Difference between evaluated pavement structure and computed pavement structure is 0.04 in SN.
This is 1.27 cm less in Road bed, therefore, evaluated pavement structure has enough strength for 10 years life period.

## B-37 Summary of Pavement Structure & Maintenance (Asphalt Concrete)

| | Erdene - Baganuur | Section 1 | Section 2 | | Section 3 - 12 | | | Section 13-21 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | STA. 112+127 ~STA.121+448 | STA. 121+448 ~STA.128+388 | STA. 128+678 ~STA.130+769 | STA.130+769 ~STA.237+100 | | | STA.237+100 ~STA.333+949 | | |
| | | L= 8,866 m | L= 6,940 m | L= 2,091 m | L= 62,131 m | L= 16,000 m | L= 28,200 m | L= 17,600 m | L= 33,749 m | L= 45,500 m |
| Existing condition | New Construction | Asphalt Pavement | Asphalt Pavement | Surface Treatment | New Construction | | | New Construction | | |
| | | | | | CBR = 8 | CBR = 10 | CBR = 12 | CBR = 8 | CBR = 10 | CBR = 12 |
| **Initial Pavement ( year 2005 - 2012 )** | | | | | | | | | | |
| | | Asphalt overlay | | | | | | | | |
| Asphalt concrete | - | 4.0 | 4.0 | 6.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Base course | - | - | - | - | 15.0 | 15.0 | 10.0 | 15.0 | 10.0 | 10.0 |
| Subbase | - | - | - | - | 26.0 | 20.0 | 22.0 | 23.0 | 24.0 | 20.0 |
| Total | - | 4.0 | 4.0 | 6.0 | 46.0 | 40.0 | 37.0 | 43.0 | 39.0 | 35.0 |
| **1st overlay ( year 2012 - 2019 )** | | | | | | | | | | |
| Asphalt concrete | 5.0 | 4.0 | 4.0 | 5.0 | 4.0 | 4.0 | 5.0 | 4.0 | 4.0 | 5.0 |
| **2nd overlay ( year 2019 - 2025 )** | | | | | | | | | | |
| Asphalt concrete | 5.0 | 5.0 | 5.0 | 4.0 | 5.0 | 4.0 | 5.0 | 4.0 | 4.0 | 5.0 |

## B-38 Summary of Pavement Structure & Maintenance (BST)

| Section 13-21 | | | |
|---|---|---|---|
| STA.237+100<br>~STA.333+949 | | | |
| Existing condition | L= 17,600 m | L= 33,749 m | L= 45,500 m |
| | New Construction | | |
| | CBR = 8 | CBR = 10 | CBR = 12 |

| Initial Pavement ( year 2005 - 2008 ) | | | |
|---|---|---|---|
| | | | |
| Bituminous Surface Treatment | 2.5 | 2.5 | 2.5 |
| Base course | 15.0 | 10.0 | 10.0 |
| Subbase | 23.0 | 24.0 | 20.0 |
| Total | 40.5 | 36.5 | 32.5 |

| 1st overlay ( year 2008 - 2011 ) | | | |
|---|---|---|---|
| Bituminous Surface Treatment | 2.0 | 2.0 | 2.0 |

| 2nd overlay ( year 2011 - 2014 ) | | | |
|---|---|---|---|
| Bituminous Surface Treatment | 2.0 | 2.0 | 2.0 |

| 3rd overlay ( year 2014 - 2017 ) | | | |
|---|---|---|---|
| Bituminous Surface Treatment | 2.0 | 2.0 | 2.0 |

| 4th overlay ( year 2017 - 2020 ) | | | |
|---|---|---|---|
| Bituminous Surface Treatment | 2.0 | 2.0 | 2.0 |

| 5th overlay ( year 2020 - 2023 ) | | | |
|---|---|---|---|
| Bituminous Surface Treatment | 2.0 | 2.0 | 2.0 |

| 6th overlay ( year 2023 - 2025 ) | | | |
|---|---|---|---|
| Bituminous Surface Treatment | 2.0 | 2.0 | 2.0 |

## B-39 Pavement Condition Factor : Cx

**1. Baganuur - Jargartkhaan**

| Case | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | 7 years | | 10 years | | 13 years | | 15 years | |
| Pavement Layer | CBR = 8 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 15.2 | 15.2 | 17.8 | 17.8 | 20.3 | 20.3 | 20.3 | 20.3 |
| Granular Subbase | 21.6 | 21.6 | 23.1 | 23.1 | 24.4 | 24.4 | 27.9 | 27.9 |
| Total | 41.8 | 0.96 | 45.9 | 0.96 | 49.7 | 0.96 | 53.2 | 0.95 |
| | CBR = 10 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 15.0 | 15.0 | 15.2 | 15.2 | 17.8 | 17.8 | 17.8 | 17.8 |
| Granular Subbase | 15.2 | 15.2 | 20.6 | 20.6 | 21.6 | 21.6 | 24.9 | 24.9 |
| Total | 35.2 | 0.95 | 40.8 | 0.96 | 44.4 | 0.95 | 47.7 | 0.94 |
| | CBR = 12 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 12.7 | 12.7 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| Granular Subbase | 14.2 | 14.2 | 15.5 | 15.5 | 20.6 | 20.6 | 23.4 | 23.4 |
| Total | 31.9 | 0.95 | 35.7 | 0.95 | 40.8 | 0.95 | 43.6 | 0.94 |
| | CBR = 14 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 10.2 | 10.2 | 12.7 | 12.7 | 15.2 | 15.2 | 15.2 | 15.2 |
| Granular Subbase | 15.0 | 15.0 | 15.7 | 15.7 | 16.0 | 16.0 | 19.1 | 19.1 |
| Total | 30.2 | 0.94 | 33.4 | 0.95 | 36.2 | 0.94 | 39.3 | 0.93 |

**2. Jargartkhaan - Undrukhaan**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CBR = 8 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 15.2 | 15.2 | 15.2 | 15.2 | 17.8 | 17.8 | 17.8 | 17.8 |
| Granular Subbase | 17.8 | 17.8 | 24.1 | 24.1 | 25.1 | 25.1 | 28.2 | 28.2 |
| Total | 38.0 | 0.96 | 44.3 | 0.96 | 47.9 | 0.95 | 51.0 | 0.95 |
| | CBR = 10 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 12.7 | 12.7 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| Granular Subbase | 16.3 | 16.3 | 17.5 | 17.5 | 22.6 | 22.6 | 25.4 | 25.4 |
| Total | 34.0 | 0.95 | 37.7 | 0.96 | 42.8 | 0.95 | 45.6 | 0.94 |
| | CBR = 12 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 12.2 | 12.2 | 12.7 | 12.7 | 12.7 | 12.7 | 15.2 | 15.2 |
| Granular Subbase | 12.7 | 12.7 | 16.7 | 16.7 | 21.6 | 21.6 | 20.1 | 20.1 |
| Total | 29.9 | 0.94 | 34.4 | 0.95 | 39.3 | 0.94 | 40.3 | 0.93 |
| | CBR = 14 | | | | | | | |
| Asphalt Concrete Surface | 5.0 | 3.3 | 5.0 | 3.3 | 5.0 | 2.8 | 5.0 | 2.2 |
| Granular Base Course | 10.2 | 10.2 | 12.7 | 12.7 | 12.7 | 12.7 | 12.7 | 12.7 |
| Granular Subbase | 12.4 | 12.4 | 13.0 | 13.0 | 17.5 | 17.5 | 20.1 | 20.1 |
| Total | 27.6 | 0.94 | 30.7 | 0.95 | 35.2 | 0.94 | 37.8 | 0.93 |

## B-40 Pavement Condition Factor of Baganuur Existing Pavement : Cx

**1. Baganuur Asphalt Pavement**

| **Case** | **1** | | **2** | | **3** | |
|---|---|---|---|---|---|---|
| Pavement Layer | Existing | | 1st overlay | | 2nd Overlay | |
| Asphalt Concrete Surface | 12.0 | 4.0 | 4.8 | 2.4 | 4.8 | 2.4 |
| Base Course | 20.0 | 20.0 | 32.0 | 30.4 | 36.8 | 35.0 |
| Subbase | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| Total | 62.0 | 0.87 | 66.8 | 0.94 | 71.6 | 0.94 |

**2. Baganuur DBST Pavement**

| **Case** | **1** | | **2** | | **3** | |
|---|---|---|---|---|---|---|
| Bituminous Surface Treatment | 7.0 | 2.3 | 5.8 | 2.9 | 5.3 | 2.9 |
| Base Course | 20.0 | 20.0 | 27.0 | 25.7 | 32.8 | 31.2 |
| Subbase | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Total | 52.0 | 0.91 | 57.8 | 0.93 | 63.1 | 0.94 |

## B-5 Breakdown of Road Construction and Maintenance Cost

### B-41 Maintenance Cost (All Asphalt Concrete in Tg)

(in Tg)

| year | Cumulative | Erdene-Baganuur | Section 1 | Section 2 | | Section 3 -12 | | | Section 13 -21 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ac Surface | BST | CBR=8 | CBR=10 | CBR=12 | CBR=8 | CBR=10 | CBR=12 | |
| Section Length ( m ) | | 36,800 | 9,321 | 6,940 | 2,091 | 62,131 | 16,000 | 28,200 | 17,600 | 33,749 | 45,500 | 258,332 |
| Bridge Length (m) | | 103 | 15 | 0 | 0 | 286 | 53 | 15 | 0 | 53 | 0 | 525 |
| Pavement length (m) | | 36,697 | 9,306 | 6,940 | 2,091 | 61,845 | 15,947 | 28,185 | 17,600 | 33,696 | 45,500 | 257,807 |
| Maintenance Cost | 4cm | - | 34,340 | 34,340 | 34,340 | 36,548 | 36,548 | - | 36,548 | 36,548 | - | |
| | 5cm | 39,660 | 39,660 | 39,660 | 39,660 | 42,324 | - | 42,324 | - | - | 42,324 | |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2007 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2008 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2009 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | 7 | 727,701,510 | 159,784,020 | 119,159,800 | 41,464,530 | 1,130,155,530 | 291,415,478 | 596,450,970 | 321,622,400 | 615,760,704 | 962,871,000 | 4,966,385,942 |
| 2013 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2016 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2018 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2019 | 14 | 727,701,510 | 184,537,980 | 137,620,200 | 35,902,470 | 1,308,763,890 | 291,415,478 | 596,450,970 | 321,622,400 | 615,760,704 | 962,871,000 | 5,182,646,602 |
| 2020 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2021 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2024 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 1,455,403,020 | 344,322,000 | 256,780,000 | 77,367,000 | 2,438,919,420 | 582,830,956 | 1,192,901,940 | 643,244,800 | 1,231,521,408 | 1,925,742,000 | 10,149,032,544 |

## B-42 Maintenance Cost (All Asphalt Concrete in US$)

(in US$)

| year | Cumulative | Erdene-Baganuur | Section 1 | Section 2 | | Section 3 -12 | | | Section 13 -21 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ac Surface | BST | CBR=8 | CBR=10 | CBR=12 | CBR=8 | CBR=10 | CBR=12 | |
| Section Length ( m ) | | 36,800 | 9,321 | 6,940 | 2,091 | 62,131 | 16,000 | 28,200 | 17,600 | 33,749 | 45,500 | 258,332 |
| Bridge Length (m) | | 103 | 15 | 0 | 0 | 286 | 53 | 15 | 0 | 53 | 0 | 525 |
| Pavement length (m) | | 36,697 | 9,306 | 6,940 | 2,091 | 61,845 | 15,947 | 28,185 | 17,600 | 33,696 | 45,500 | 257,807 |
| Maintenance Cost | 4cm | - | 34,340 | 34,340 | 34,340 | 36,548 | 36,548 | - | 36,548 | 36,548 | - | |
| | 5cm | 39,660 | 39,660 | 39,660 | 39,660 | 42,324 | - | 42,324 | - | - | 42,324 | |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2007 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2008 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2009 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2012 | 7 | 661,547 | 145,258 | 108,327 | 37,695 | 1,027,414 | 264,923 | 542,228 | 292,384 | 559,782 | 875,337 | 4,514,896 |
| 2013 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2015 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2016 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2018 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2019 | 14 | 661,547 | 167,762 | 125,109 | 32,639 | 1,189,785 | 264,923 | 542,228 | 292,384 | 559,782 | 875,337 | 4,711,497 |
| 2020 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2021 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2024 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 1,323,094 | 313,020 | 233,436 | 70,334 | 2,217,199 | 529,846 | 1,084,456 | 584,768 | 1,119,565 | 1,750,675 | 9,226,393 |

## B-43 Maintenance Cost (Asphalt Concrete + BST in Tg)

(in Tg)

| year | Cumulative | Erdene-Baganuur | Section 1 | Section 2 | | Section 3 -12 | | | Section 13 -21 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ac Surface | BST | CBR=8 | CBR=10 | CBR=12 | CBR=8 | CBR=10 | CBR=12 | |
| Section Length ( m ) | | 36,800 | 9,321 | 6,940 | 2,091 | 62,131 | 16,000 | 28,200 | 17,600 | 33,749 | 45,500 | 258,332 |
| Bridge Lengt (m) | | 103 | 15 | 0 | 0 | 286 | 53 | 15 | 0 | 53 | 0 | 525 |
| Pavement length (m) | | 36,697 | 9,306 | 6,940 | 2,091 | 61,845 | 15,947 | 28,185 | 17,600 | 33,696 | 45,500 | 257,807 |
| Maintenance Cost | 4cm | - | 34,340 | 34,340 | 34,340 | 36,548 | 36,548 | - | 17,668 | 17,668 | 17,668 | |
| | 5cm | 39,660 | 39,660 | 39,660 | 39,660 | 42,324 | - | 42,324 | - | - | - | |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2007 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2008 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155,478,400 | 297,670,464 | 401,947,000 | 855,095,864 |
| 2009 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155,478,400 | 297,670,464 | 401,947,000 | 855,095,864 |
| 2012 | 7 | 727,701,510 | 159,784,020 | 119,159,800 | 41,464,530 | 1,130,155,530 | 291,415,478 | 596,450,970 | 0 | 0 | 0 | 3,066,131,838 |
| 2013 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155,478,400 | 297,670,464 | 401,947,000 | 855,095,864 |
| 2015 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2016 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155,478,400 | 297,670,464 | 401,947,000 | 855,095,864 |
| 2018 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2019 | 14 | 727,701,510 | 184,537,980 | 137,620,200 | 35,902,470 | 1,308,763,890 | 291,415,478 | 596,450,970 | 0 | 0 | 0 | 3,282,392,498 |
| 2020 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155,478,400 | 297,670,464 | 401,947,000 | 855,095,864 |
| 2021 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155,478,400 | 297,670,464 | 401,947,000 | 855,095,864 |
| 2024 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 1,455,403,020 | 344,322,000 | 256,780,000 | 77,367,000 | 2,438,919,420 | 582,830,956 | 1,192,901,940 | 932,870,400 | 1,786,022,784 | 2,411,682,000 | 11,479,099,520 |

## B-44 Maintenance Cost (Asphalt Concrete + BST in US$)

(in US$)

| year | Cumulative | Erdene-Baganuur | Section 1 | Section 2 | | Section 3 -12 | | | Section 13 -21 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ac Surface | BST | CBR=8 | CBR=10 | CBR=12 | CBR=8 | CBR=10 | CBR=12 | |
| Section Length ( m ) | | 36,800 | 9,321 | 6,940 | 2,091 | 62,131 | 16,000 | 28,200 | 17,600 | 33,749 | 45,500 | 258,332 |
| Bridge Lengt (m) | | 103 | 15 | 0 | 0 | 286 | 53 | 15 | 0 | 53 | 0 | 525 |
| Pavement length (m) | | 36,697 | 9,306 | 6,940 | 2,091 | 61,845 | 15,947 | 28,185 | 17,600 | 33,696 | 45,500 | 257,807 |
| Maintenance Cost | 4cm | - | 34,340 | 34,340 | 34,340 | 36,548 | 36,548 | - | 17,668 | 17,668 | 17,668 | |
| | 5cm | 39,660 | 39,660 | 39,660 | 39,660 | 42,324 | - | 42,324 | - | - | - | |
| 2005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2006 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2007 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2008 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141,344 | 270,610 | 365,406 | 777,360 |
| 2009 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2010 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2011 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141,344 | 270,610 | 365,406 | 777,360 |
| 2012 | 7 | 661,547 | 145,258 | 108,327 | 37,695 | 1,027,414 | 264,923 | 542,228 | 0 | 0 | 0 | 2,787,393 |
| 2013 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2014 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141,344 | 270,610 | 365,406 | 777,360 |
| 2015 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2016 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141,344 | 270,610 | 365,406 | 777,360 |
| 2018 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2019 | 14 | 661,547 | 167,762 | 125,109 | 32,639 | 1,189,785 | 264,923 | 542,228 | 0 | 0 | 0 | 2,983,993 |
| 2020 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141,344 | 270,610 | 365,406 | 777,360 |
| 2021 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141,344 | 270,610 | 365,406 | 777,360 |
| 2024 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | | 1,323,094 | 313,020 | 233,436 | 70,334 | 2,217,199 | 529,846 | 1,084,456 | 848,064 | 1,623,657 | 2,192,438 | 10,435,545 |