8-4. 構造実験

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1. 概要

CNCRP プロジェクトの一環として、第 2 年次（2012 年）に既存 RC 造を想定した計 7 体、第 3 年次（2013 年）に耐震補強試験体 2 体を含む計 6 体の縮小模型を用いた静的繰返し水平加力実験を行った。

1.1 実験の背景

プロジェクトの第 1 年次にダッカ（バ国）で一般的な既存 RC 造（築 20~30 年程度）の耐震診断の適用に関して課題を抽出した。脆弱性評価での技術面の課題は、低強度コンクリートによる柱の高軸力比、丸鋼の仕様、レンガ壁による柱の短柱化、柱せん断補強筋の 90 度フック、せん断補強筋のない接合部の評価等であった。これらは骨組みの強度・靭性の評価に大きく影響する。しかし日本を含めて既往の実験・研究成果が少なく、また当地での実験データは皆無であった。既存 RC 造の強度・靭性の適切な評価のためには CNCRP プロジェクトとして構造実験を行う必要があった。

1.2 実験目的

1. 構造実験を通して既存 RC 造骨組の耐震性評価に必要な、強度・靭性に関する有用なデータを得る。
2. 耐震補強の試験体（2013 年実験の 2 体）の実験を通して耐震補強効果を確認する。
3. 「バ」の実状を反映した RC 造構造実験の公開と周知を通して、バ国技術者に RC 構造物の水平荷重と水平たわみの非線形な挙動の理解を進め、耐震性評価に関する能力開発に資する。
4. 実験の成果を、耐震診断マニュアルと耐震改修設計マニュアルの作成に反映させる。

1.3 実験の実施

実験は 1990 年頃に JICA が贈与した BUET Civil Engineering laboratory 内の鉄骨反力骨組（土木構造用）を改造して行った。実験に協力的であった BUET と実験に関する覚書（MOU）を締結した。加力装置として既存の油圧ジャッキが水平方向 25 トン x 2 セット、鉛直方向 50 トン x 2 セットを利用した。計測用の主要な変位計、ダイアルゲージ、歪ゲージは日本から持ち込んだ。データロガーは BUET 所有のものを利用した。実験の加力は、BUET の技師（テクニシャン）、計測は BUET・DUET の学生（院生、傭人）が行う計画とした。

加力の制御は BUET 側に依頼する計画であったが、工程管理を含めて結局専門家が行った。

試験体の詳細は C/P（PWD）の既存 RC 造に関する意見を参考にして専門家で設計し現地再委託で試験体を製作した。試験体の設置・撤去は再委託で行った。

1.4 制約

バ国で初めての RC 造建築物を対象にした静的繰返し加力実験を 2012 年、2013 年に行った。

（その後 2013 年から HBRI でも構造実験を開始したことを確認している）

実験に習熟するまで試行錯誤しながら経験を蓄積していった。

加力装置：反力骨組みの大きさから試験体寸法に制約があること、加力装置とくに水平方向のジャッキの能力に制約（仕様は 25 トン、実際は 23 トン）があり補強試験体は寸法に制約があること。

鉛直加力の垂直性、試験体設置架台の水平性等、実験結果の精度に影響する要因があった。

試験体製作：試験体製作については約 1/3 スケールを採用したが特にせん断補強筋径を実情に合わせて縮小させることは困難であった。

計測：ダイアルゲージ、変位計の一部が機能していない場合もあった。荷重―たわみ曲線をその場で見て加力制御することはできなかった。データロガーからのデータ取り出しに 2012 年実験では日数が（2 か月）かかった。2012 年の歪ゲージは取付け不良（防水不良）があり機能しなかった。2012 年実験では鉛直荷重の加力で試験体頭部が破損し鉛直荷重に制約がでた。

1.5 成果

1. 2012 年、2013 年実験を通して、RC 造骨組みの強度・靭性についての有用なデータが得られた。特に靭性については実験的アプローチが有用である。
2. 耐震補強として、RC 壁と鉄骨ブレースの強度増加効果を確認できた。
3. 2012 年は実験を公開し多くの参加者が実験を見学した（2013 年は政情不安のため不実施）。また技術討論会を 2013 年、2014 年に実施し参加者に実験結果を紹介できた。
4. 実験の成果を耐震診断マニュアル、耐震改修設計マニュアルに反映できた。
5. しかし既存 RC 造の耐震性評価についてまだ多くの課題が残されており、今後のバ国での自主的な実験的研究を継続して実施することが望まれる。

1.6 実験の公開

2012 年 11 月 19 日に BUET 実験室内にて実験内容の説明と公開を行った。2013 年は政情不安定のため実験の公開は見送った。

1.7 技術討論会

第 2 年次は 2013 年 2 月 3 日（実験目的、背景の説明を含む）、第 3 年次は 2014 年 2 月 10 日（改修設計マニュアルへの反映、耐震判定指標の考えを含む）に技術者、研究者を招いて PWD 大ホールで実施し、実験内容の紹介と意見交換を行った。

以下、英文資料。

Part 1: Summary of Structural Experiment 2013

Part 2: Experiment of year 2013

Part 3: Experiment of year 2012

Report of

Structural Experiments on 2012 and 2013 by CNCRP

March 2014

Revised in June 2015

CNCRP (PWD and JICA)

Contents

Part 1 Summary of Structural Experiment, 2013

Structural experiment was conducted in 2012 and 2013 by CNCRP. Following is the summary of year 2013.

1) Frame model

Existing mid-rise RC frame, a scaled 1 span 1 story frame model has been selected for the structural experiment.

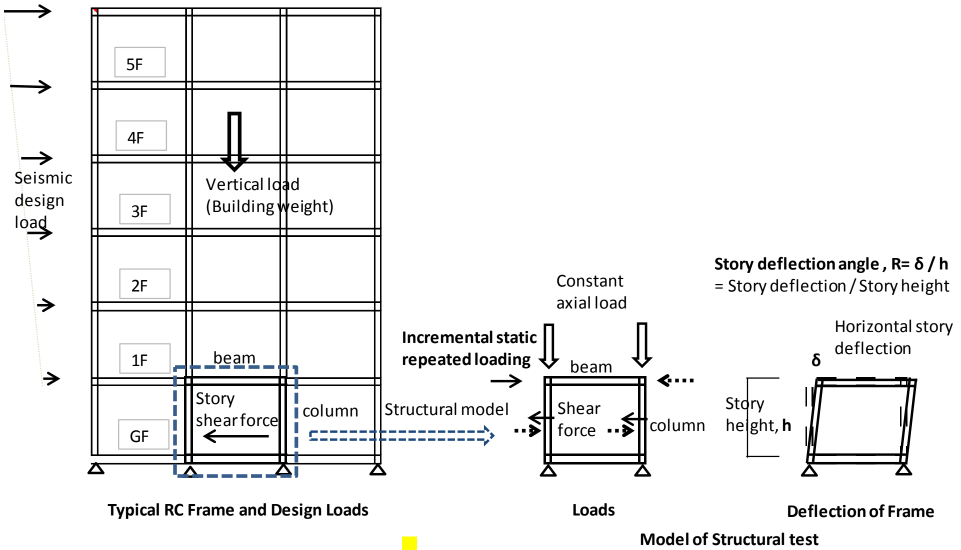


Figure 1 Test model

2) Testing apparatus

Load-meter and dial gauge relation has been controlled at the lab. Load-cell and displacement Transducer has been recorded by data-logger.

Constant vertical load (N=16 tonf) and repeated static incremental horizontal loading were provided.

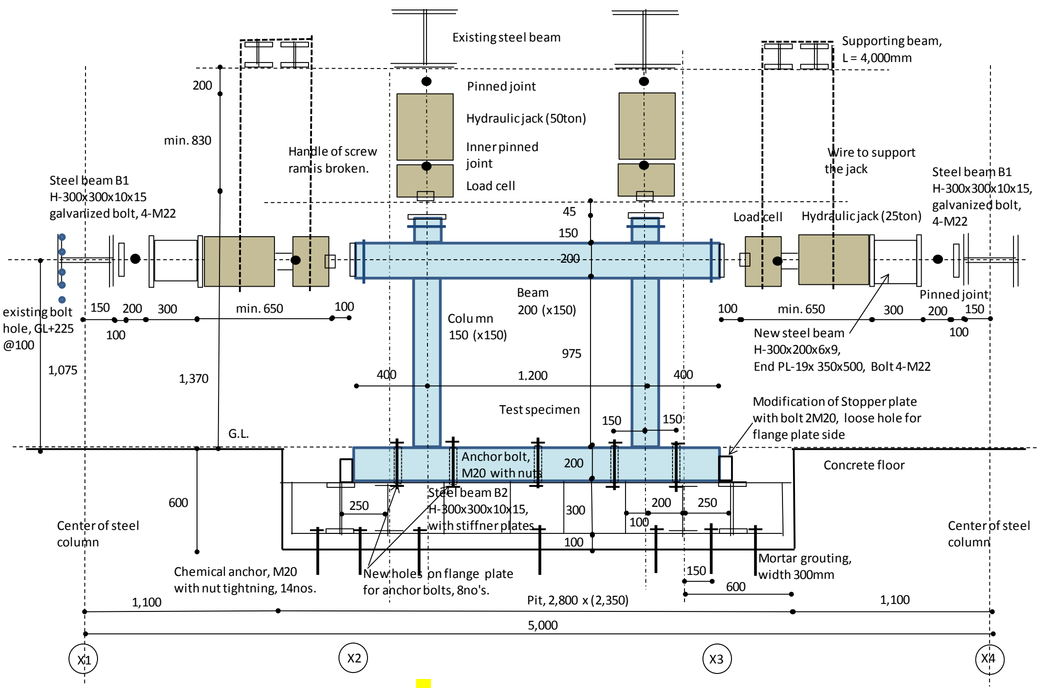


Figure 2 Testing Apparatus, unit (mm)

3) Specimen, total 6 specimens including 2 specimens for retrofit were tested in 2013.

Specimen No.1 is a standard specimen of a typical frame. Column size is 150mmx150mm. Beam size is 150mmx200mm. Specimen No.2 is expressing end frame that anchor of beam main re-bar to column is 180 degree hook. Specimen No.3 has brick standing wall with thickness 65mm, and the height is 3/4 of clear height. Glass window is installed at the opening. Specimen No.4 has brick wall without no opening. Specimen No.5 is a retrofitted specimen by RC wall. Specimen No.6 is a retrofitted specimen by steel framed brace. Because of the capacity limitation of the horizontal hydraulic jacks, relatively low strength retrofit was planned.

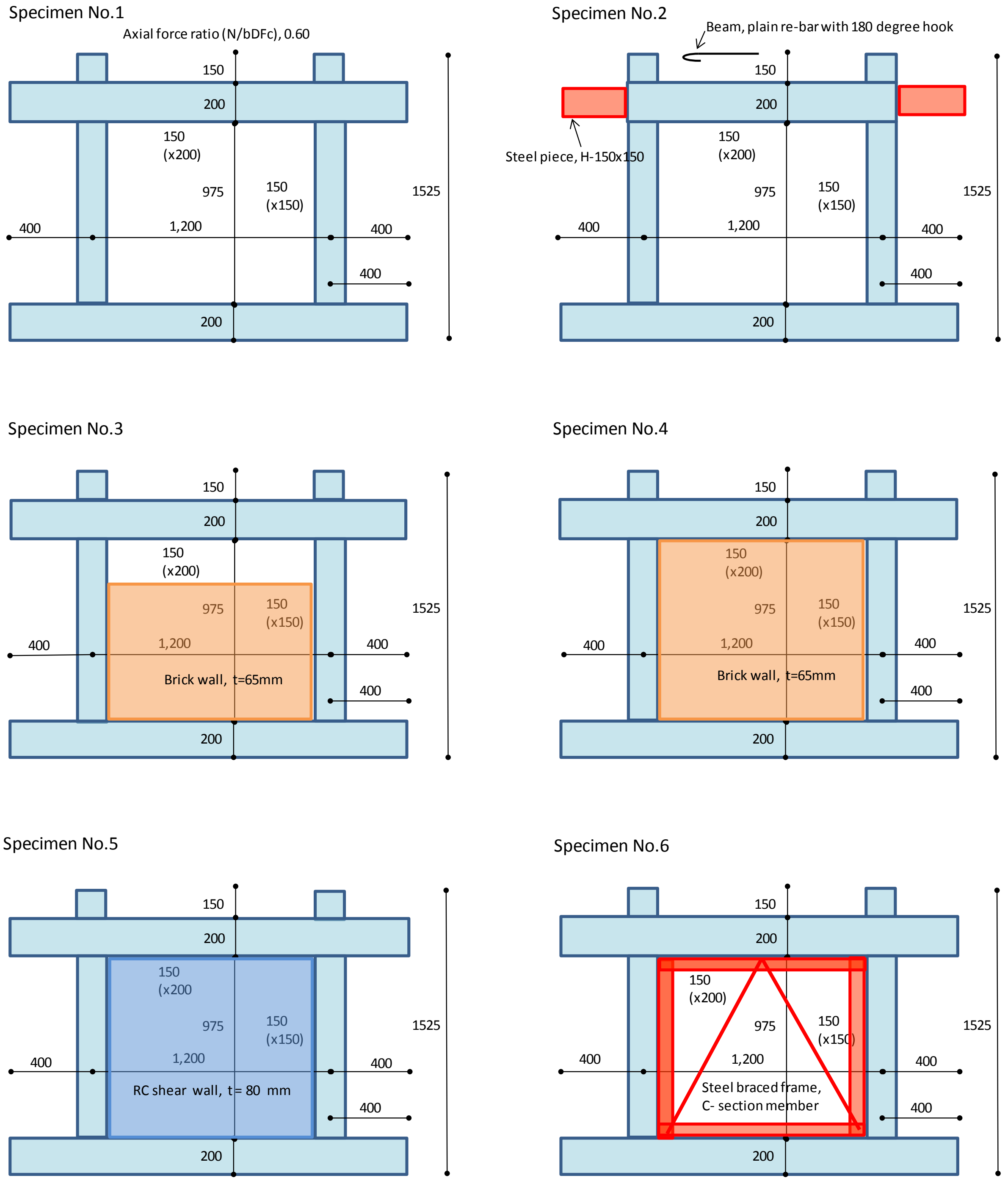


Figure 3 Test Specimen

Low strength concrete of 10.8N/mm2 was casted. High axial force ratio (N/b*D*Fc=0.68) was realized. Poor shear reinforcement was supposed. Joint of plain bars is lap joint. Column tie was changed to @195 instead of @150, due to the use of re-bar φ7.45mm, from No.1 to No.6. Detail of specimen No.1 is shown below.

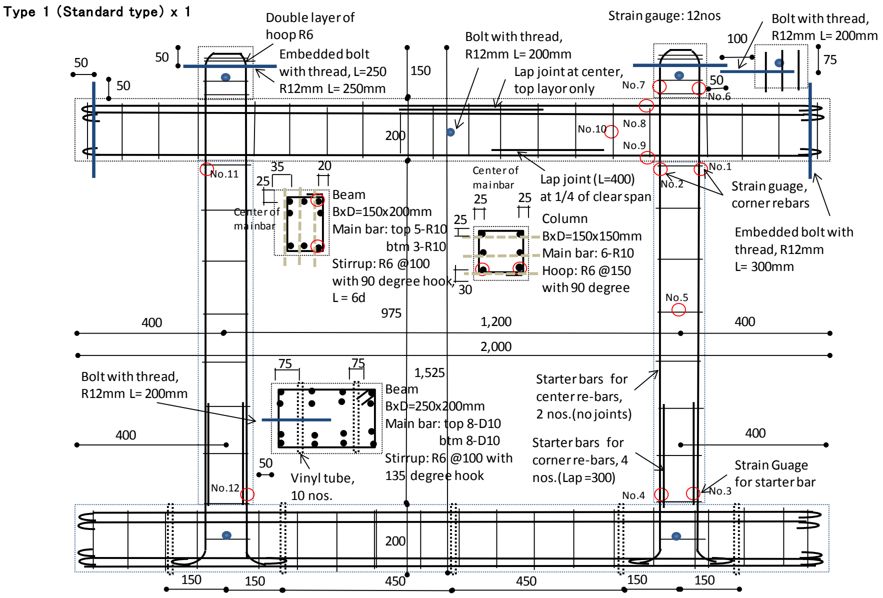


Figure 4 Test Specimen No.1

4) Horizontal load and deflection curve (Unit: tonnage and mm)

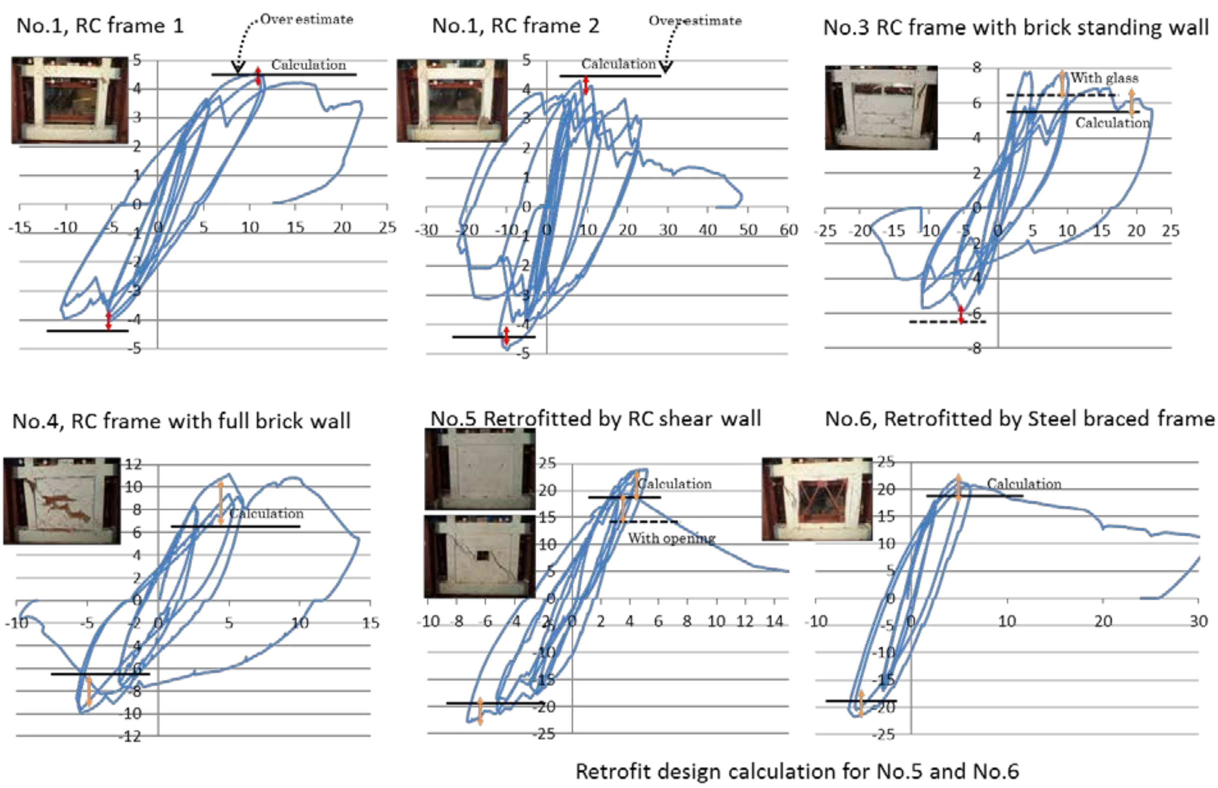


Figure 5 Horizontal load and deflection curve

Outline (displacement shown is the reading value of the dial gauge at upper side of beam)

Specimen No. 1:

R<1/100 (δ< 11.75m), max. load was positive 4.5ton and negative 4.0ton. Flexural cracks occurred at top and bottom of columns. Vertical cracks also occurred at bottom of columns. Diagonal crack occurred at the top of column. Diagonal crack at left column occurred at R< 1/200 (δ< 5.88mm).

R<1/50 (δ<23.5mm), shear failure at the top of right column occurred at positive 3.5 at (25.7mm), and the vertical load dropped.

Specimen No. 2:

R<1/100 (δ< 11.75m), max. load was observed positive 3.9ton and negative 5.0ton. Diagonal crack extended at both side of beam column panel zone, and strength dropped from 3.5 ton (at 7.8mm) to 3.0 ton (12.4mm). Flexural cracks occurred at bottom of columns.

R<1/50 (δ<23.5mm), Diagonal crack extended at both panel zone. Cover concrete at bottom of column (especially rear side) was detached.

R<1/25 (δ<47.0mm), Bottom of column was failed. Cracks of panel zone were extended. Vertical load was reduced at (30mm).

Specimen No. 3:

R<1/200 (δ< 5.88mm), max. load was positive 7.7ton and negative was 6.0 ton. Cracks extended for columns and brick walls.

R<1/100 (δ< 11.75m), Diagonal and vertical crack extended on right column. Many flexural cracks at left column observed.

R<1/50 (δ<23.5mm) , Positive load 7.0ton and dropped to 5.8 ton due to the Glass broken. Shear failure of right column occurred at (– 17.1mm) of negative loading, and vertical load was also dropped.

Specimen No. 4:

R<1/200 (δ< 5.88mm), max. load at positive was 11.0ton, and negative was 10.0 ton. Diagonal crack occurred at top of left column. Cracks extended on brick wall.

R<1/100 (δ<11.75mm), Shear failure occurred at let column at (10mm) of positive loading. Big diagonal crack extended on brick wall and bottom of right column. At negative loading, horizontal stiffness decreased and could not support the vertical load.

Specimen No. 5:

R<1/200 (δ< 5.88mm), max. load was positive 23.3ton(limit of jack, at 4.3mm) and negative was 21.2ton. Horizontal crack observed at left column, diagonal crack developed at wall. Small square hole was provided on the wall at the lab. to reduce the strength, and loaded again. Shear failure occurred at positive loading 19.6 ton at 5.0mm. Axial load started the drop at around 8mm.

Specimen No. 6:

R<1/200 (δ< 5.88mm), max. load was positive 22.0ton at (5.2mm), and negative load was 22.0ton at (6.2mm). New diagonal crack occurred at middle of left column at 3rd positive cycle. Slight Buckling of out of plain direction of left bracing was observed.

R < 1/100 (δ< 11.75mm), Shear failure occurred at left column at positive 20 ton at (9.0mm).

Buckling of left vertical steel frame was observed. Yield of left side brace and out of plain direction buckling at right side steel bracing was observed. Horizontal crack beneath the beam at grout mortal was observed. Vertical load drop started at 20.9mm.

5) Evaluation of Horizontal Strength

Horizontal strength of each specimen was calculated as follows. Calculated value is shown as horizontal line on Figure 5.

Calculated strength of **specimen No.1** as flexural failure was slightly over estimated, possible reason will be the use of plain bar and lap joint of main bar. Calculated strength of **specimen No.2** was also slightly over estimated. It was supposed some drop of strength due to the anchor of beam re-bar, but there was no clear reduction of the strength in this specimen. **Specimen No.3** was evaluated as flexural failure column and shear failure column. Contribution of the strength of window with frame was not negligible, which was estimated as 1.2 ton. **Specimen No.4** was estimated as shear failure column at both side, and excessive strength was the contribution of brick wall. **Specimen No.5** is the shear failure column at both side and shear failure RC wall. Strength evaluation without opening and with opening seems reasonable. Strength evaluation of **Specimen No.6** is the summation of shear failure strength of both column and strength of brace (yield strength of tension side and buckling strength of compression side). Strength evaluation seems reasonable.

Column

Flexural strength is calculated by Eq. A1.1-1 of the J. Standard, Shear strength of column is calculated by Eq. A1.1-1 of the J. Standard. Estimated collapse mechanism of the frame is shown in Figure 6.

Shear wall for retrofit

Shear strength of concrete panel plus column shear strength, shear strength of post-installed anchor and grout mortar are calculated.

Steel framed brace for retrofit

Steel brace of tension and compression (buckling strength) plus column shear strength, shear strength of stud/ post-installed anchor and grout mortar are calculated.

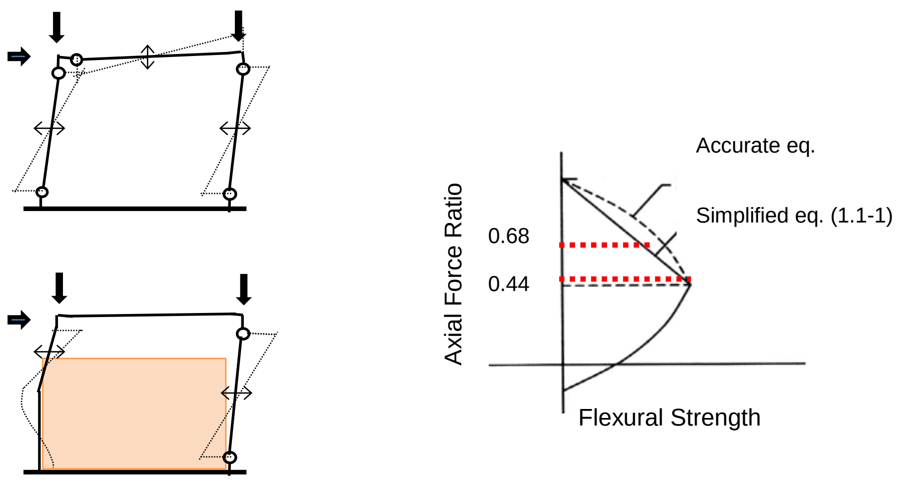


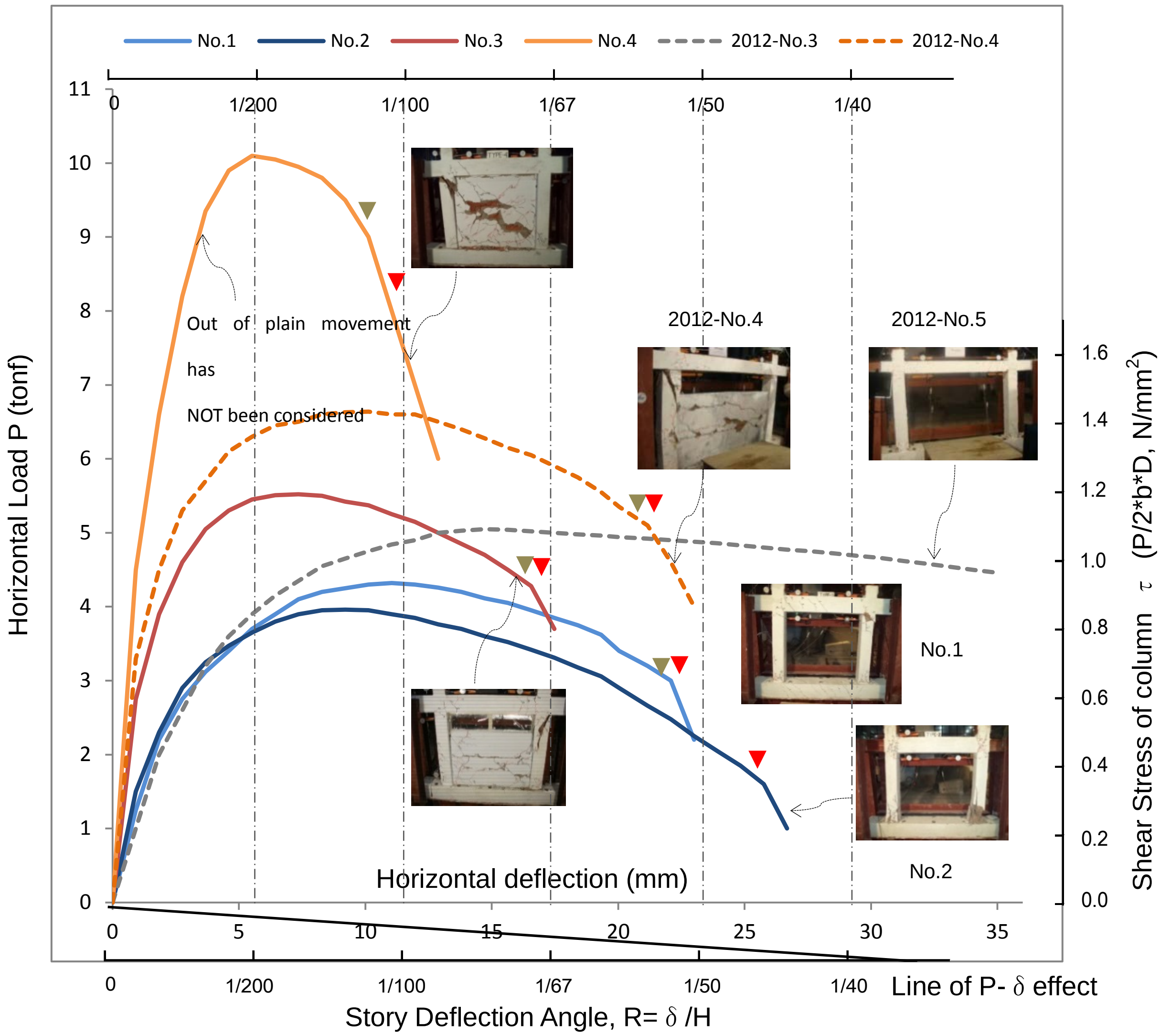
Figure 6 Estimated collapse mechanism of frame and M-N interaction curve

6) Simplified Monotonic Horizontal Load- Deflection Curve

Following simplified monotonic loading-deflection curve is estimated based on the result of cyclic loading and incorporating the engineering judgment.

Axial force ratio: Specimen No.1 ~ No.4, **N/ (b*D*Fc) = 0.68** (**Fc=10.6N/mm^2**, N=163kN)

Specimen 2012-No.4, 5, N/ (b*D*Fc) = 0.44 (Fc=16.5N/mm^2, N=163kN)



Note: Marking: ▼denotes a point of "Drop in vertical strength".

▼ denotes a point of "Shear failure" by the visual observation.

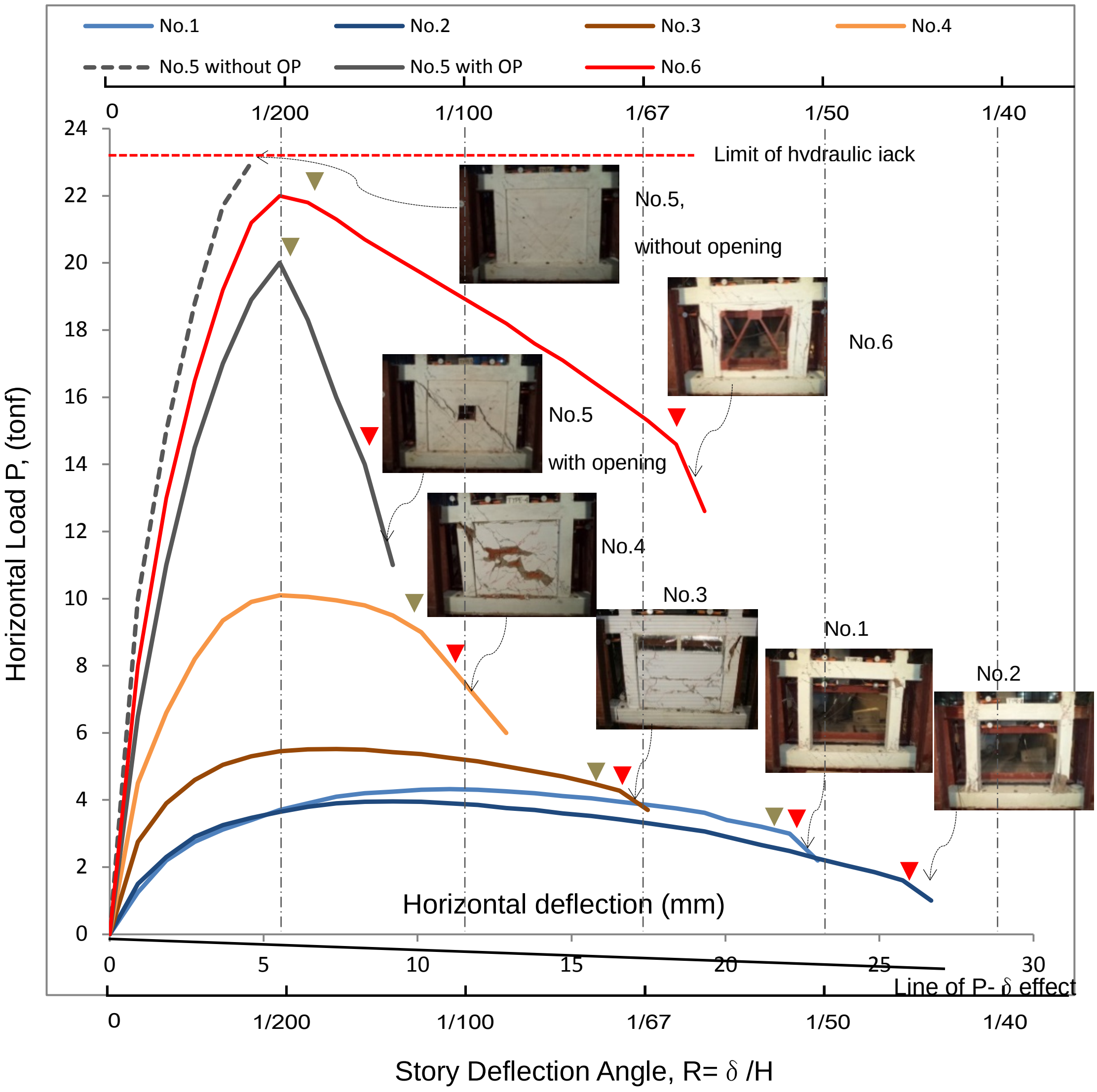
R: Story deflection angle = Horizontal deflection (mm)/ Story height (1,175mm)

b*D: Width and depth of column (mm* mm)

Fc: Concrete strength (N/mm^2)

1tonf = 2, 205lbf=9.8kN, 1Mpa= 1N/mm2, 1N/mm2 = 145 psi

Figure 7 Simplified Monotonic Load- Deflection Curve (1/2)



Note: Marking: ▼denotes a point of "Drop in vertical strength".

▼ denotes a point of "Shear failure" by the visual observation.

R: Story deflection angle = Horizontal deflection (mm)/ Story height (1,175mm)

b*D: width and depth of column (mm* mm)

Fc: Concrete strength (N/mm^2)

Axial force ratio: Specimen No.1 ~ No.6, N/ (b*D*Fc) = 0.68 (Fc=10.6N/mm^2, N=163kN)

Retrofit: Specimen No.5, Fc of wall =10.7N/mm^2

Figure 7 Simplified Monotonic Load- Deflection Curve (2/2)

7) Summary

Basic experiment for the seismic evaluation and retrofit design of existing RC buildings in Dhaka was done. Summary is as follows.

(1) Specimen and loading:

1. RC frame of plain bar and low strength concrete (fc=10.6N/mm2) with/without brick-wall.
2. High axial force ratio (N/b*D*fc) of column 0.68.
3. Repeated horizontal load is provided until the point of drop in vertical load (= drop of floor).

(2) Results:

1. Horizontal load- story deflection angle relation was shown.
2. High axial force ratio causes low ductility of frame in addition to strength reduction.
3. Shear failure of column causes the drop in vertical strength.
4. Brick-wall affects the behavior of frame, with respect to stiffness, strength and ductility.

(3) Retrofit:

1. RC shear wall and steel braced frame is effective to increase shear strength of frames, but reduce the deformability, if no column jacketing, in case of vulnerable column.

(4) Strength evaluation:

1. Flexural and shear strength of column, shear strength of RC wall and strength of steel brace including connection for retrofit were evaluated and compared with test results.
2. Flexural strength by the calculation will be reduced in case of low strength concrete.

(5) The Issue to be investigated further :

1. Strength of beam column connection, evaluation of poor quality control at sites. Quantitative evaluation of 90 degree hook of column tie, use of plain main bar and lap joint.
2. Ductility evaluation of above item 1.

(6) Limitation of the Tests

Material (Def. of low strength concrete, less than 13.5 N/mm^2)

1. Concrete; low strength concrete, 10.6 N/mm^2 at 8 weeks. For information, 16.5N/mm^2 in 2012.

	Yield stress	Original requirement	2012
2. Plain Re-bar φ 10mm	σy = 350N/mm^2		327 N/mm^2
3. Plain Re-bar φ 7.4mm	σy = 353N/mm^2	φ 6mm	(560 N/mm^2)
4. Deformed re-bar D10mm	σy = 274N/mm^2		387 N/mm^2
5. Steel angle plate 4.2mm	σy = 363 N/mm^2	3.0mm, σy =250N/mm^2	

Interval of shear reinforcement (column tie) and detail of steel bracing were modified accordingly.

Loading

1. Inclination of foundation beam under the specimen; Slight inclination of foundation steel beam was observed in plane and out of plane direction, and filler plates were provided where a gap exists under the specimen.
2. Limitation of horizontal hydraulic jacks; capacity was 23 ton (230kN) only.

Part 2 Experiment of year 2013

2.1 General

Testing plan, load-deflection curve, material test, and strength evaluation are introduced at here.

2.2 Testing plan

Revised: Specimen No.2, numbering of strain gauges, bridge box, strain gauge bonding (8/28)

Numbering of DT/DG, name of specimen, appendix: fabrication of specimen (10/24)

1) Purpose

2nd structural experiment is conducted to supplement the 1st test of existing building and to evaluate the effect of retrofitting.

2) Outline

1. Reinforced concrete frame with 1 story, 1span will be selected for the experiment.
2. Mid-rise buildings constructed around 25 years ago, and 1/3 scale frame and 1/2 scale of member.

3) Test Specimen

Total 6 set of RC frames are planned.

Column size; 150mmx150mm、beam size; 150mm x 200mm (previous size was 150mmx150mm)

Capping portion of column will be reinforced or concrete casting will be properly done to ensure the loading of axial force.

1. Axial force ratio 0.6, common to each specimen, to show strength decrease after the peak of load-deflection curve. (previous one was 0.43).
2. Anchoring of beam main bar, anchoring of beam main bar with hook to column and slippage.
3. Brick wall type 1, brick standing wall with 65mm, height 3/4 of cleat height, possibility of shear failure of column in case of not strong beam.
4. Brick wall type 2, brick wall without opening, thickness 65mm, increase of stiffness and strength, used for the evaluation of soft story.
5. Retrofit by RC shear wall, strength increase.
6. Retrofit by steel braced frame, strength increase.

4) Material

Concrete: Trial mix of 3 types will be conducted to get low strength concrete of 11~12N/mm2 at 8 weeks (original design strength is 14N/mm2). Water cement ratio including moisture volume of aggregates will be controlled. (Concrete strength of 2012 was 16.5N/mm2, and low strength concrete was not achieved). Mix design will be decided after the result of 3 types of trial mix.

Concrete work: Concreting shall be casted in one day for total 6 specimens, to reduce the deviation of concrete strength. Formwork shall be prepared for 6 sets. Curing of concrete will be 8 weeks before loading.

Re-bar: Material procurement shall be done soon after the selection of the contractor. Re-bar test shall be done soon for plain bar 10mm, 6mm and deformed bar 10mm.

Re-bar material and steel plate shall be provided to JET for the test in Japan.

Steel: Tensile test shall be done for the piece of structural steel for retrofitting. Test piece shall be provided to JET for the test in Japan.

Bond test: simple test of bond strength for lap joint of re-bar and re-bar anchor with hook.

5) Model (typical)

1. Column, size: 150mmx150mm, Main bars: 6-φ10mm (round bar),
Shear reinforcement: φ6mm @150 with 90 degree hook
2. Beam, size: 150mmx 200mm
   Main bars: top 5-φ10mm top and 5-φ10mm bottom
   Shear reinforcement: φ6mm @100 with 90 degree hook
3. Beam column connection; no hoop
4. Brick wall, 250x125x75mm, thickness 60mm with height of 750mm
250x60x75mm, thickness 60mm with full

6) Frame sizes, Height; 1.525m, Span; 1.2m (Span length was reduced from 1.6m to 1.2m considering the capacity of horizontal jack, 25 ton, against retrofitted specimen of No.5 and No.6.)

7) Strain gauge on re-bar

To cooperate the work for putting strain gauge on re-bar of specimen by students of BUET.

8) Displacement transducer (DT), Dial gauge (DG)

A piece of glass will be put on a specimen where DT and DG are provided.

9) Setting of a specimen

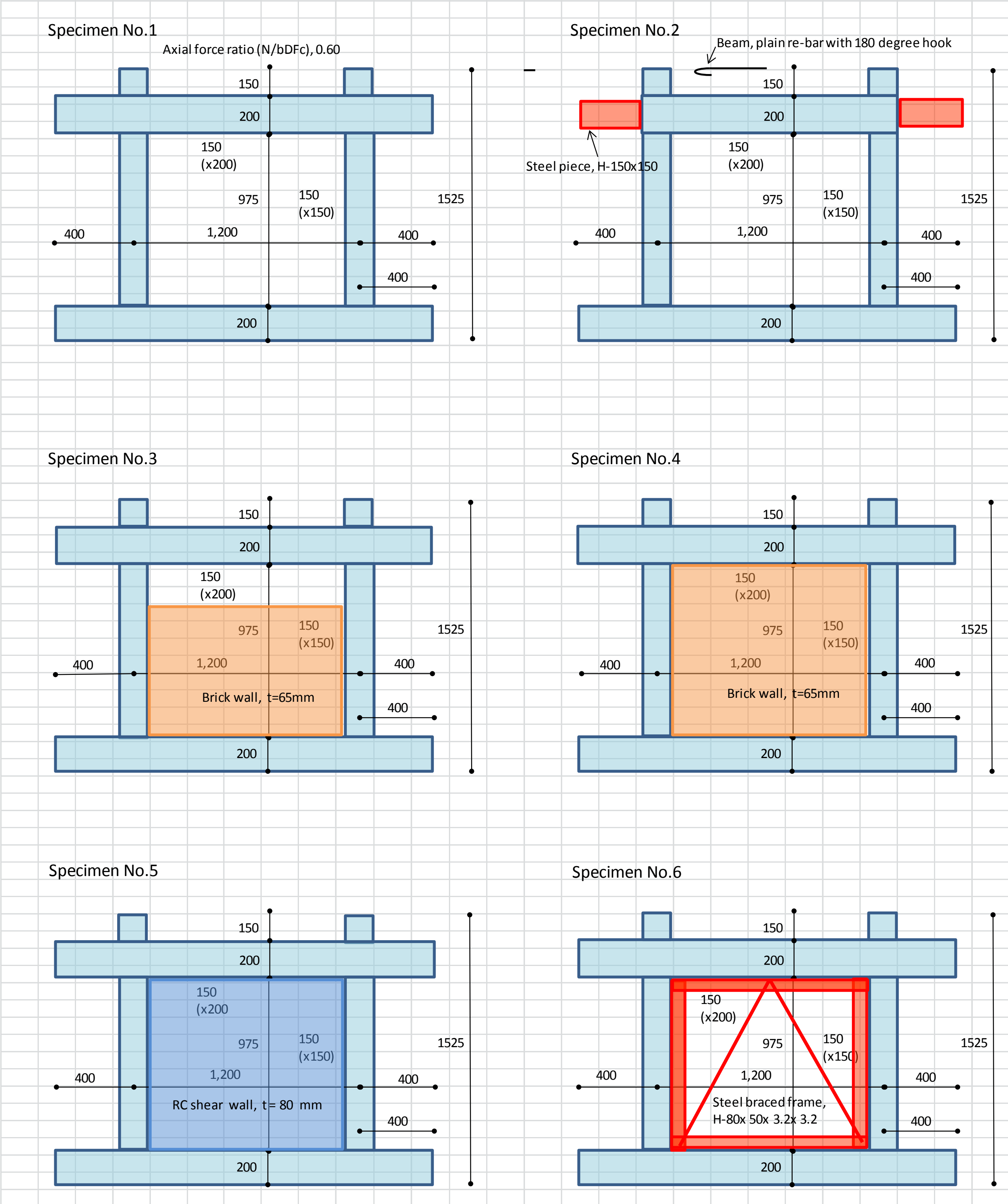
Alignment of vertical jack and specimen will be measured properly.

Note: Axial force ratio is N/bDFc.

	Axial force ratio	Beam main bar anchor	Brick wall	Retrofit	Name
No.1	0.6	nill	Nill	Nill	**F**rame0**6ST**andard
No.2	0.6	To panel zone	Nill	Nill	**F**rame0**6AN**chor
No.3	0.6	Nill	With opening	Nill	**F**rame0**6B**rick**1**
No.4	0.6	Nill	No opening	Nill	**F**rame0**6B**rick**2**
No.5	0.6	Nill	Nill	Shear wall	**F**rame0**6S**hear**W**all
No.6	0.6	Nill	Nill	Steel braced frame	**F**rame0**6S**teel**B**racedframe

10) Specimen

Total 6 specimens



11) Plan of loading

Existing reaction frame with hydraulic jack and load cell will be used.

Horizontal load; 250kN capacity, stroke 100mm, Vertical load; 500kN capacity, stroke 100mm

Additional 2 nos. of steel members for horizontal loading will be provided for the reaction frame.

12) Loading program (draft)

Repeated static incremental horizontal load is provided.

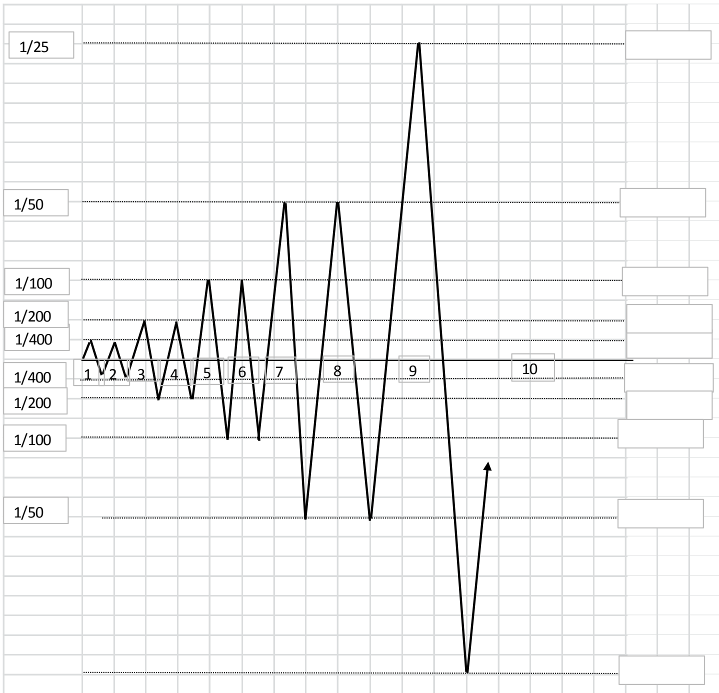
1/400 of story height 1,175mm, 2.94mm, 2 cycles (step will be controlled by load)

1/200 5.88mm, 2 cycles

1/100 11.75mm, 2 cycles

1/50 23.5mm, 2 cycles (step will be controlled by displacement)

1/25 47.0mm, 2 cycles



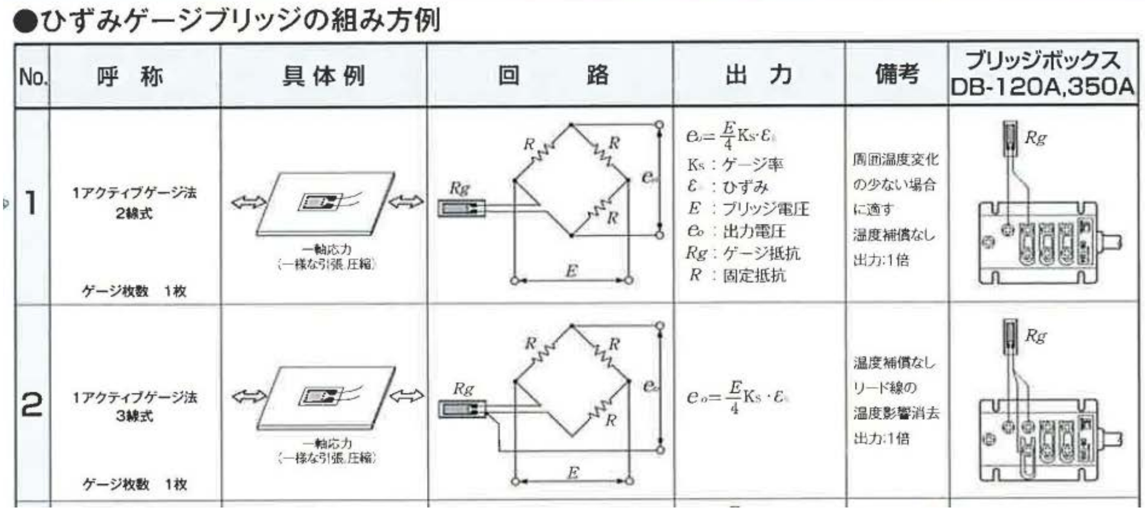
13) Place of the Experiment

Testing laboratory of Department of Civil Engineering, BUET

14) Measurement of strain of re-bar

Strain gauges are bonded to re-bars. The 3-wire system of No. 2 bridge box is adopted to minimize the impact of temperature change.

Bridge Box



●ひずみゲージブリッジの組み方例

No.	呼 称	具体例	回 路	出 力	備考	ブリッジボックス DB-120A,350A
1	1アクティブゲージ法 2線式 ゲージ枚数 1枚	一軸応力（一様な引張.圧縮）	Rg, R, R, R, e_o, E	$e_o=\frac{E}{4}Ks\cdot\varepsilon$ Ks：ゲージ率 ε：ひずみ E：ブリッジ電圧 e_o：出力電圧 Rg：ゲージ抵抗 R：固定抵抗	周囲温度変化の少ない場合に適す 温度補償なし 出力:1倍	Rg
2	1アクティブゲージ法 3線式 ゲージ枚数 1枚	一軸応力（一様な引張.圧縮）	Rg, R, R, R, e_o, E	$e_o=\frac{E}{4}Ks\cdot\varepsilon$	温度補償なし リード線の温度影響消去 出力:1倍	Rg

Kyowa Electrical Instruments Co., Ltd. Japan

Data of strain gauges for re-bars

<u>Data of strain gauge</u>

Data of strain gauges provided on re-bars are transferred to the data-logger (Dewetron) through a bridge box. Strain (mm/mm) is calculated by following equation which converts the measured voltage by data-logger (Dewetron) through bridge box to strain.

Strain ε is expressed by,

$\varepsilon=4/(E\times Ks)\times \varepsilon o$ (output voltage)

Ks(Gauge factor) = 2.08 (information by the maker of strain gauge, to be confirmed)

E(Bridge voltage) = 2.5V(2.5V will be selected as excitation by Dewetron, typical value is 2V in case of a Japanese data-logger)

$\varepsilon=4/(2.5\text{x}2.08)\times \varepsilon o$ (output voltage)

$=0.7692\times\varepsilon o$ (output voltage)

$\varepsilon=(0.7692/1000)\text{ x }\varepsilon o$ (output voltage in mV/V)

Data logger, DEWE-2600 series (BUET)

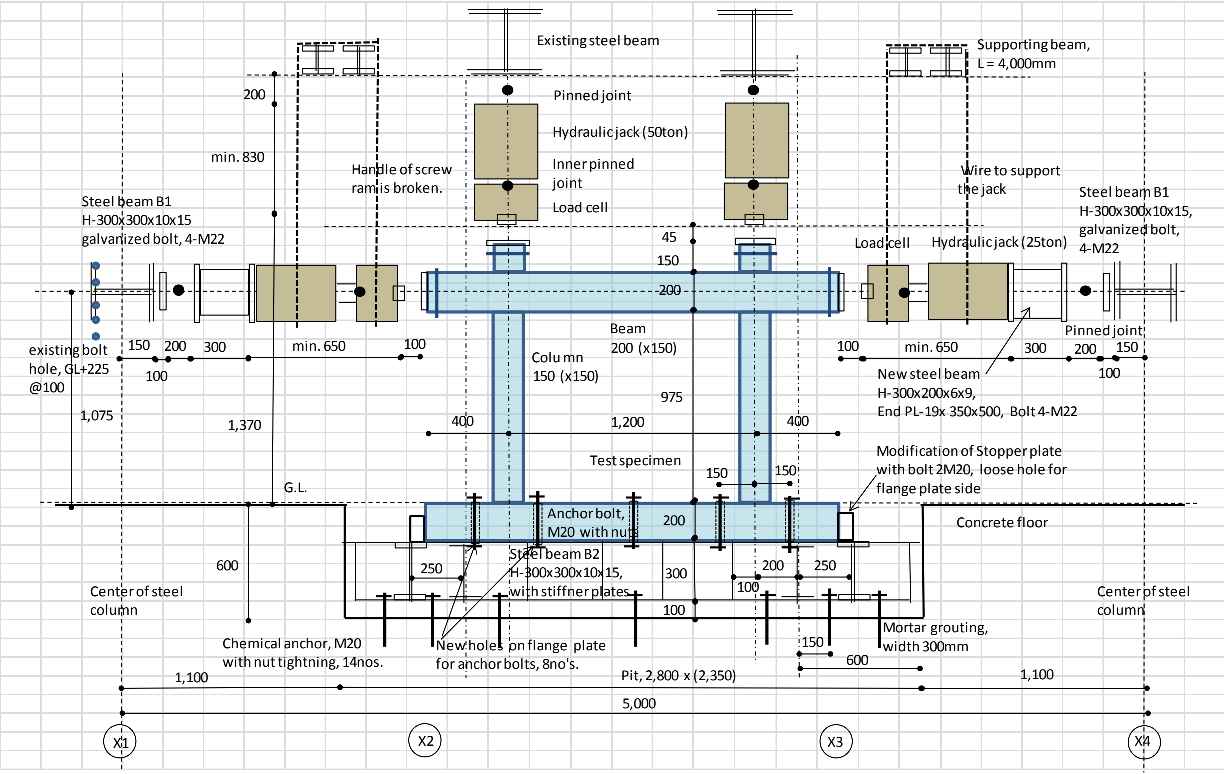
Note: 10,000 μ（10^{-6}）$=10^{-2}=1\%$

Refer to Appendix for temperature compensation gauge.

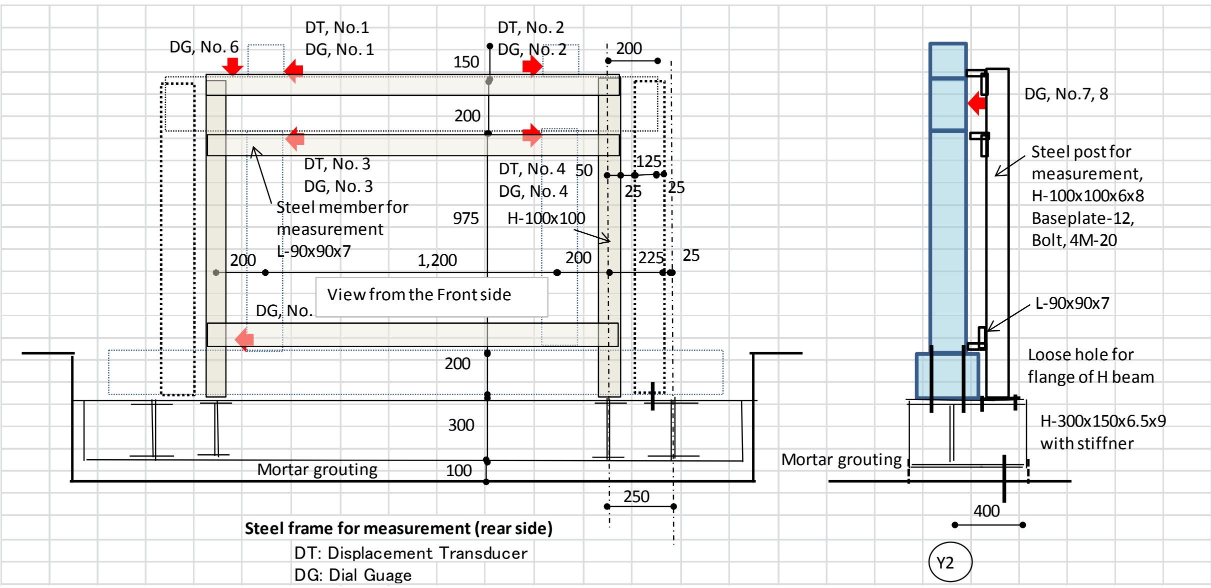
Attachment: The Drawings

1) Testing Apparatus (unit: mm)

1-1) General

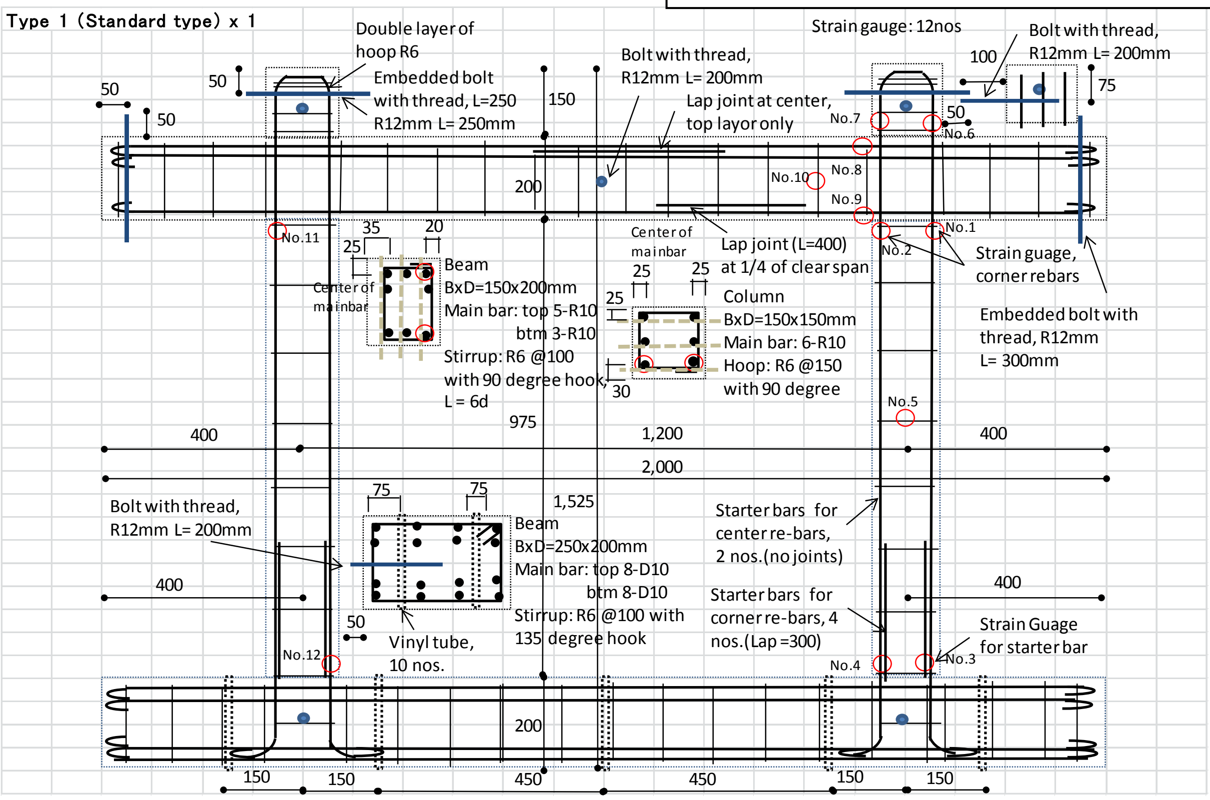


1-2) Measurement (Numbering based on the view from the front side)

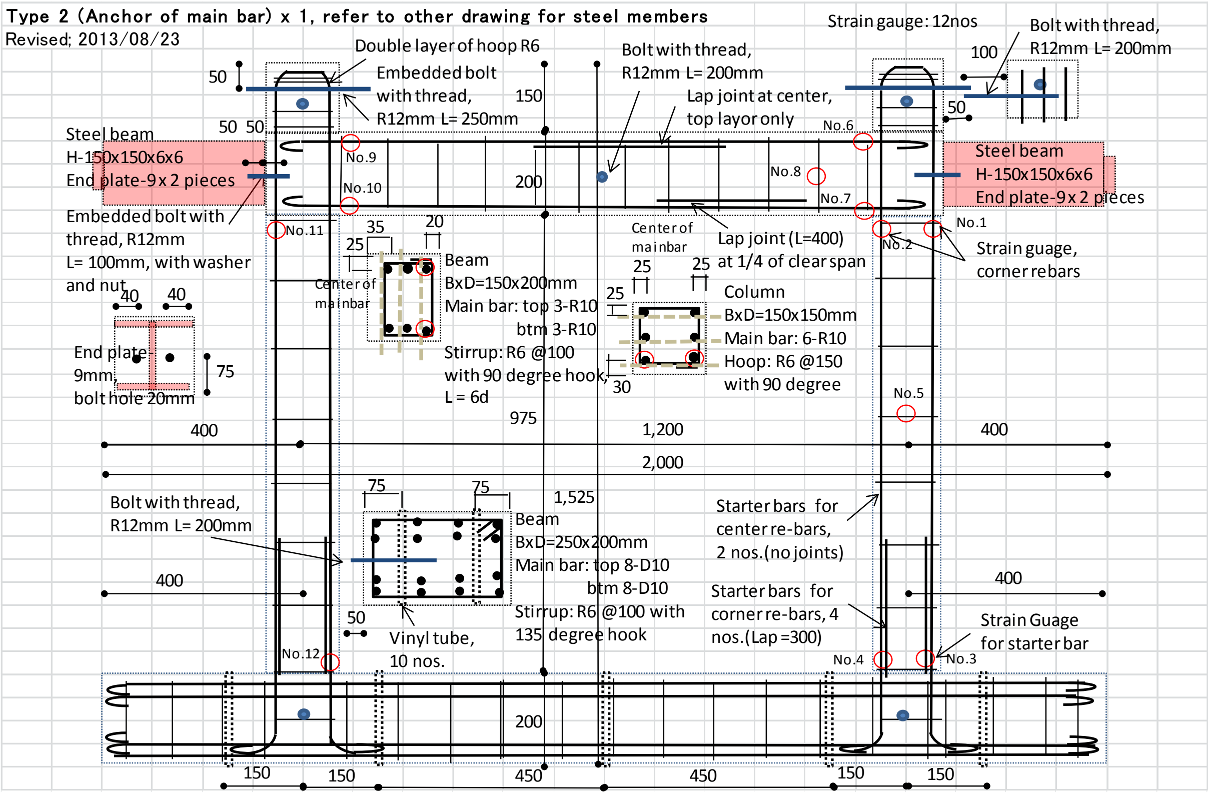


2) Specimen (unit; mm)**,** joint of main bars is lap joint.

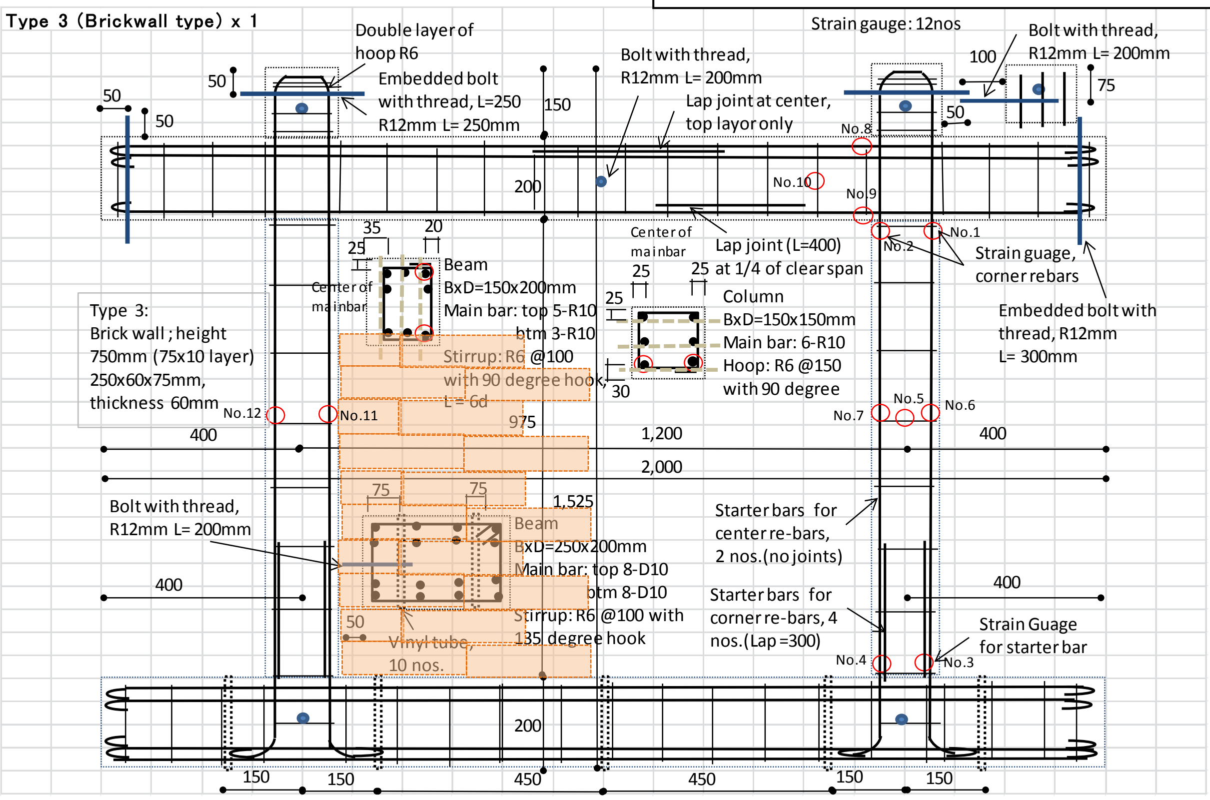
No.1



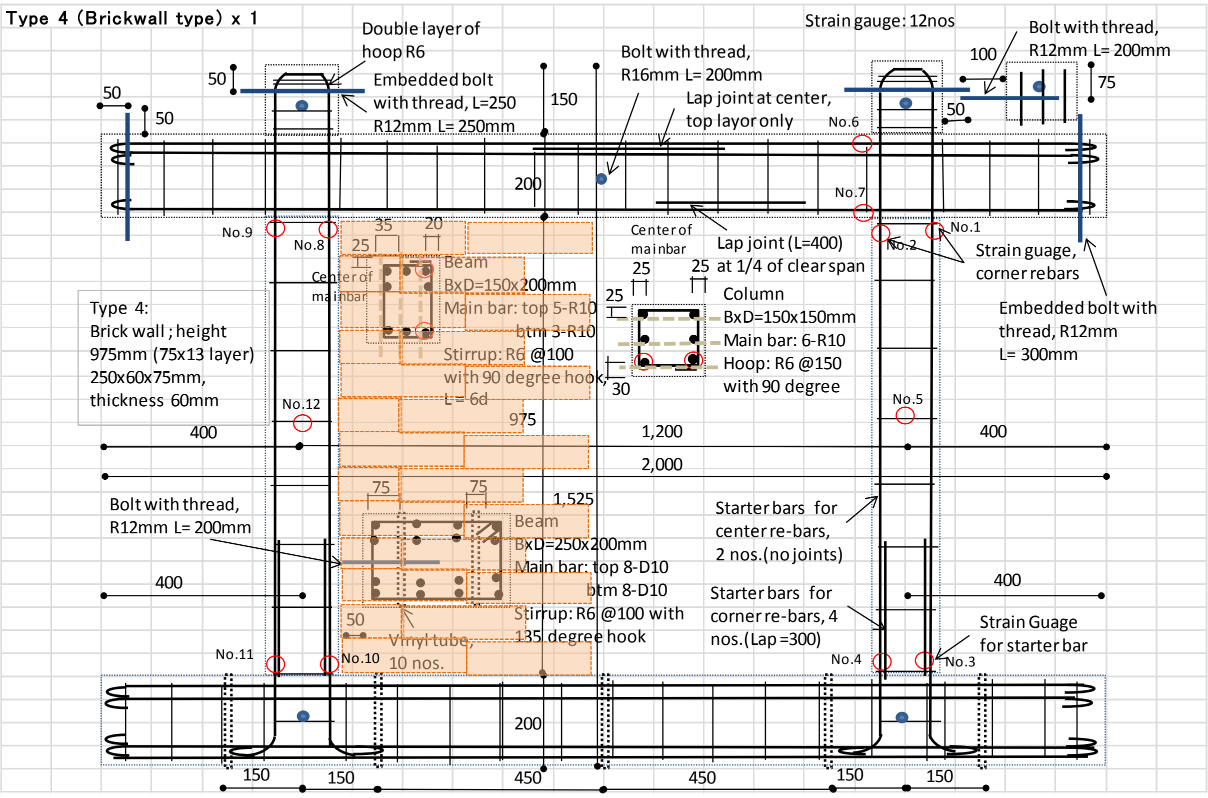
No.2



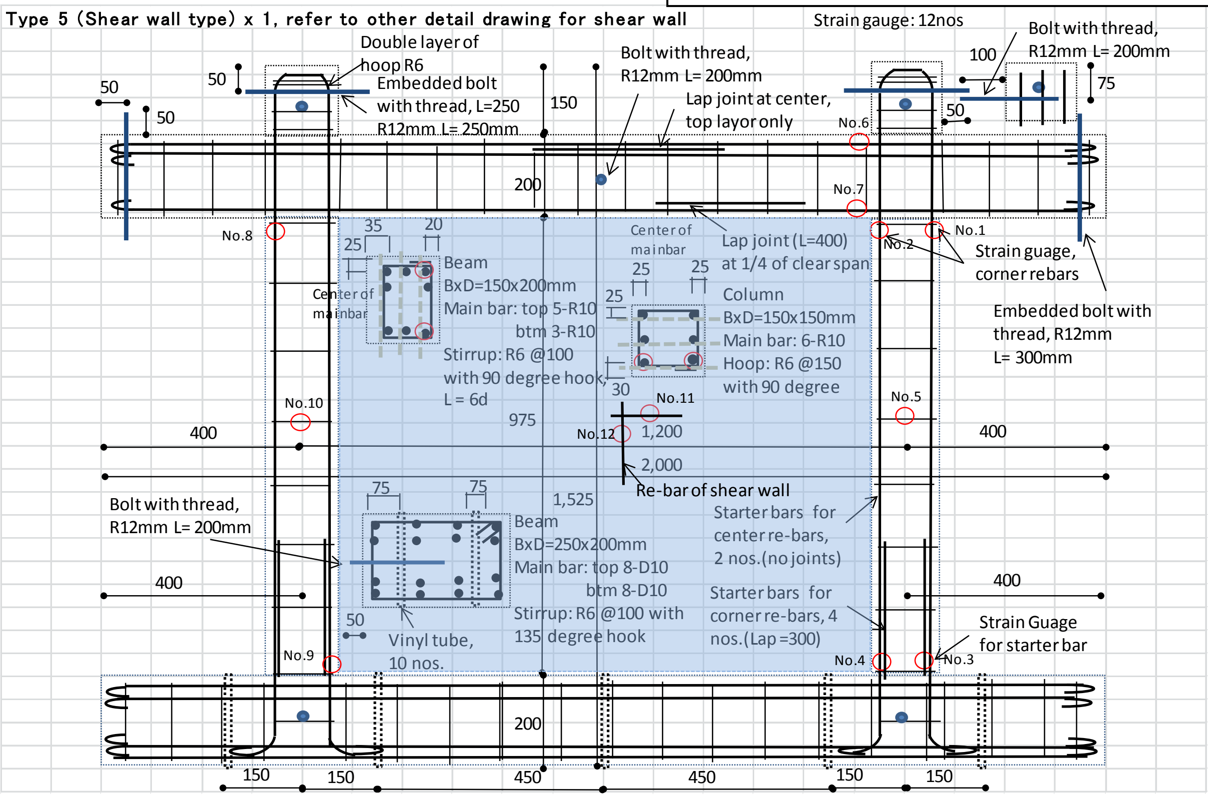
No.3


Type 3 (Brickwall type) x 1
Strain gauge: 12nos
Double layer of hoop R6
Embedded bolt with thread, L=250 R12mm L= 250mm
Bolt with thread, R12mm L= 200mm
Lap joint at center, top layor only
Bolt with thread, R12mm L= 200mm
Beam BxD=150x200mm Main bar: top 5-R10 btm 3-R10 Stirrup: R6 @100 with 90 degree hook L= 6d
Center of main bar
Lap joint (L=400) at 1/4 of clear span
Column BxD=150x150mm Main bar: 6-R10 Hoop: R6 @150 with 90 degree
Strain guage, corner rebars
Embedded bolt with thread, R12mm L= 300mm
Type 3: Brick wall ; height 750mm (75x10 layer) 250x60x75mm, thickness 60mm
Bolt with thread, R12mm L= 200mm
Beam BxD=250x200mm Main bar: top 8-D10 btm 8-D10 Stirrup: R6 @100 with 135 degree hook
Vinyl tube, 10 nos.
Starter bars for center re-bars, 2 nos. (no joints)
Starter bars for corner re-bars, 4 nos. (Lap =300)
Strain Guage for starter bar
1,200
2,000
1,525
975

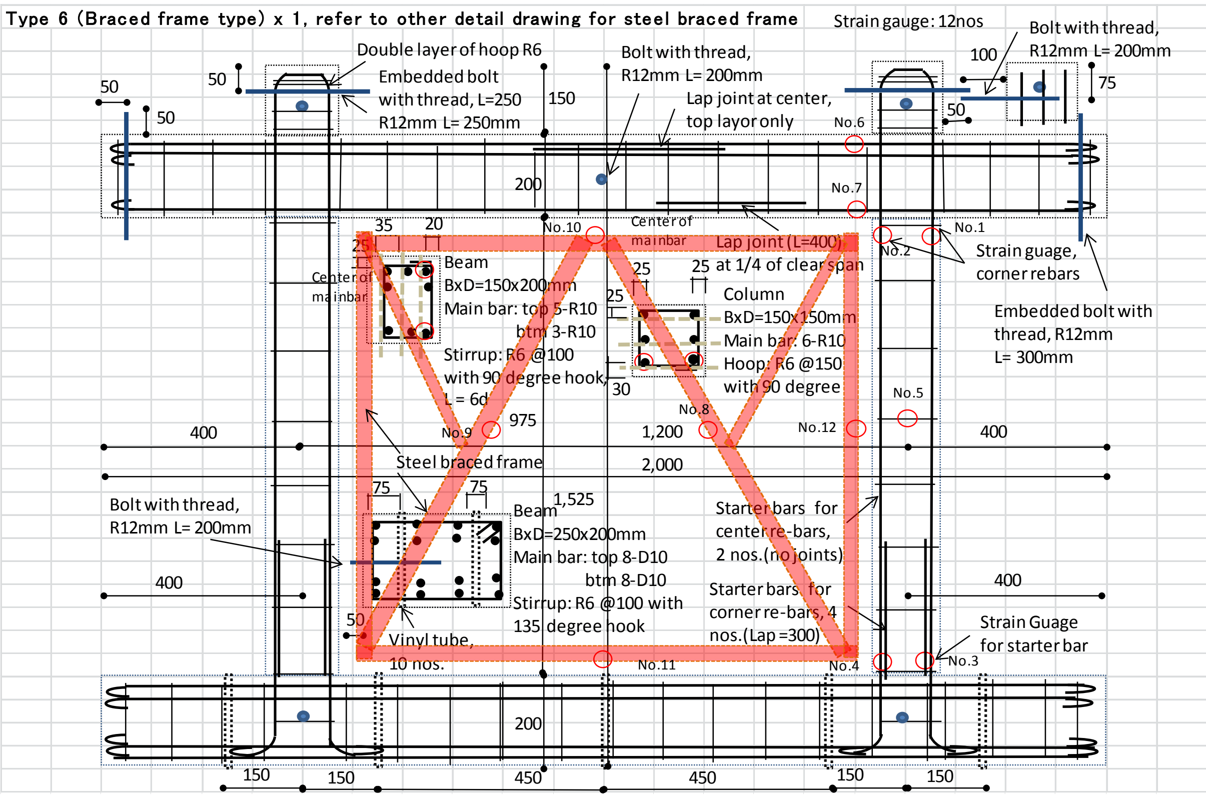
No.4


Type 4 (Brickwall type) x 1
Strain gauge: 12nos
Double layer of hoop R6
Embedded bolt with thread, L=250 R12mm L= 250mm
Bolt with thread, R16mm L= 200mm
Lap joint at center, top layor only
Bolt with thread, R12mm L= 200mm
Beam BxD=150x200mm Main bar: top 5-R10 btm 3-R10 Stirrup: R6 @100 with 90 degree hook L= 6d
Center of main bar
Lap joint (L=400) at 1/4 of clear span
Column BxD=150x150mm Main bar: 6-R10 Hoop: R6 @150 with 90 degree
Strain guage, corner rebars
Embedded bolt with thread, R12mm L= 300mm
Type 4: Brick wall ; height 975mm (75x13 layer) 250x60x75mm, thickness 60mm
Bolt with thread, R12mm L= 200mm
Beam BxD=250x200mm Main bar: top 8-D10 btm 8-D10 Stirrup: R6 @100 with 135 degree hook
Vinyl tube, 10 nos.
Starter bars for center re-bars, 2 nos. (no joints)
Starter bars for corner re-bars, 4 nos. (Lap =300)
Strain Guage for starter bar
1,200
2,000
1,525
975

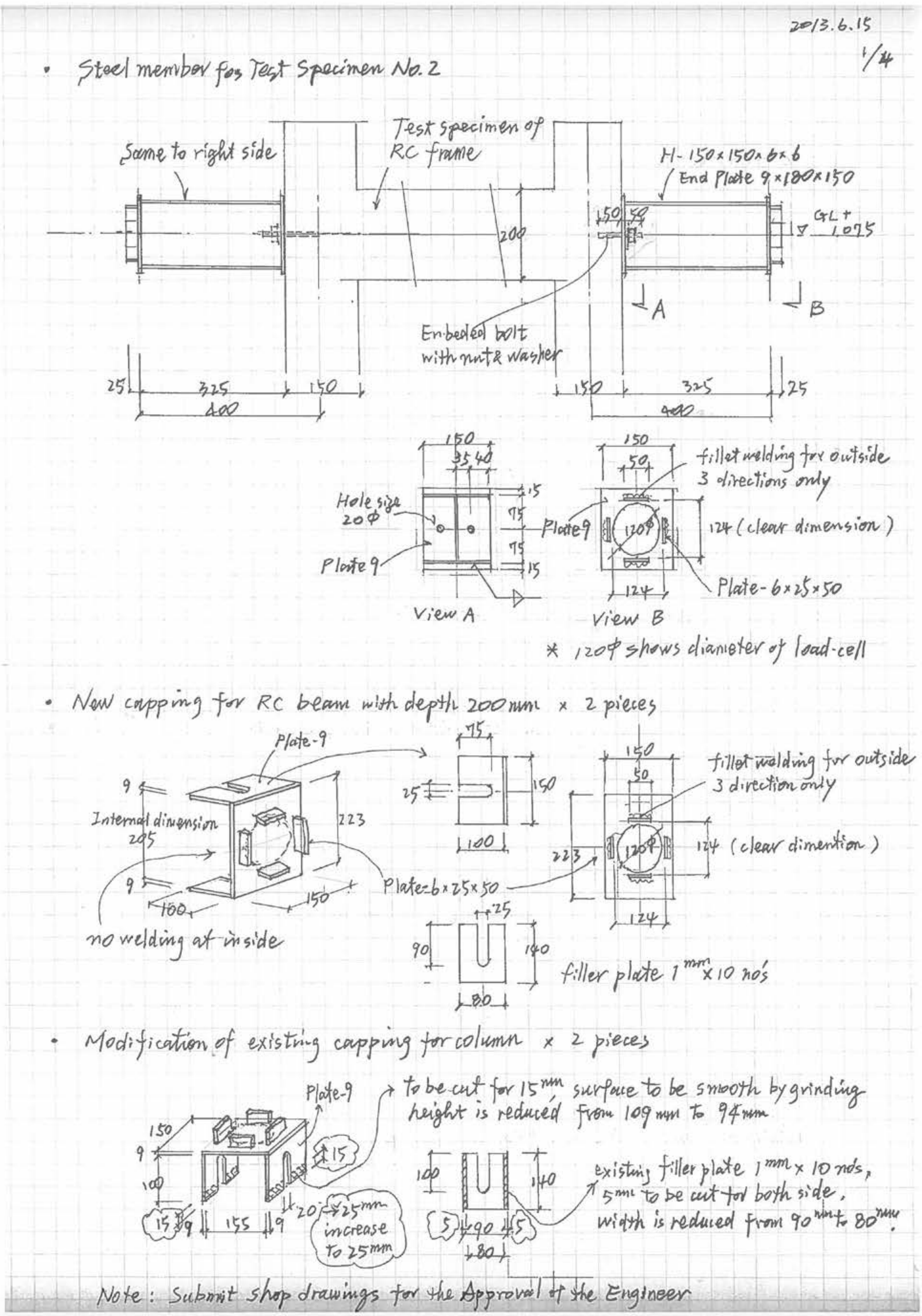
No.5


Type 5 (Shear wall type) x 1, refer to other detail drawing for shear wall
Strain gauge: 12nos
Double layer of hoop R6
Embedded bolt with thread, L=250 R12mm L= 250mm
Bolt with thread, R12mm L= 200mm
Lap joint at center, top layor only
Lap joint (L=400) at 1/4 of clear span
Strain guage, corner rebars
Embedded bolt with thread, R12mm L= 300mm
Center of mainbar
Beam BxD=150x200mm Main bar: top 5-R10 btm 3-R10 Stirrup: R6 @100 with 90 degree hook, L = 6d
Column BxD=150x150mm Main bar: 6-R10 Hoop: R6 @150 with 90 degree
Re-bar of shear wall
Beam BxD=250x200mm Main bar: top 8-D10 btm 8-D10 Stirrup: R6 @100 with 135 degree hook
Starter bars for center re-bars, 2 nos.(no joints)
Starter bars for corner re-bars, 4 nos.(Lap =300)
Vinyl tube, 10 nos.
Strain Guage for starter bar
Bolt with thread, R12mm L= 200mm
No.1 No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10 No.11 No.12
975 1,200 2,000 1,525 400 400 400 400 200 200 150 150 450 450 150 150 50 50 50 50 100 75 35 20 25 25 25 25 30 75 75

No.6


Type 6 (Braced frame type) x 1, refer to other detail drawing for steel braced frame
Strain gauge: 12nos
Double layer of hoop R6
Embedded bolt with thread, L=250 R12mm L= 250mm
Bolt with thread, R12mm L= 200mm
Lap joint at center, top layor only
Lap joint (L=400) at 1/4 of clear span
Strain guage, corner rebars
Embedded bolt with thread, R12mm L= 300mm
Center of mainbar
Beam BxD=150x200mm Main bar: top 5-R10 btm 3-R10 Stirrup: R6 @100 with 90 degree hook, L = 6d
Column BxD=150x150mm Main bar: 6-R10 Hoop: R6 @150 with 90 degree
Steel braced frame
Beam BxD=250x200mm Main bar: top 8-D10 btm 8-D10 Stirrup: R6 @100 with 135 degree hook
Starter bars for center re-bars, 2 nos.(no joints)
Starter bars for corner re-bars, 4 nos.(Lap =300)
Vinyl tube, 10 nos.
Strain Guage for starter bar
Bolt with thread, R12mm L= 200mm
No.1 No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10 No.11 No.12
975 1,200 2,000 1,525 400 400 400 400 200 200 150 150 450 450 150 150 50 50 50 50 100 75 35 20 25 25 25 25 30 75 75

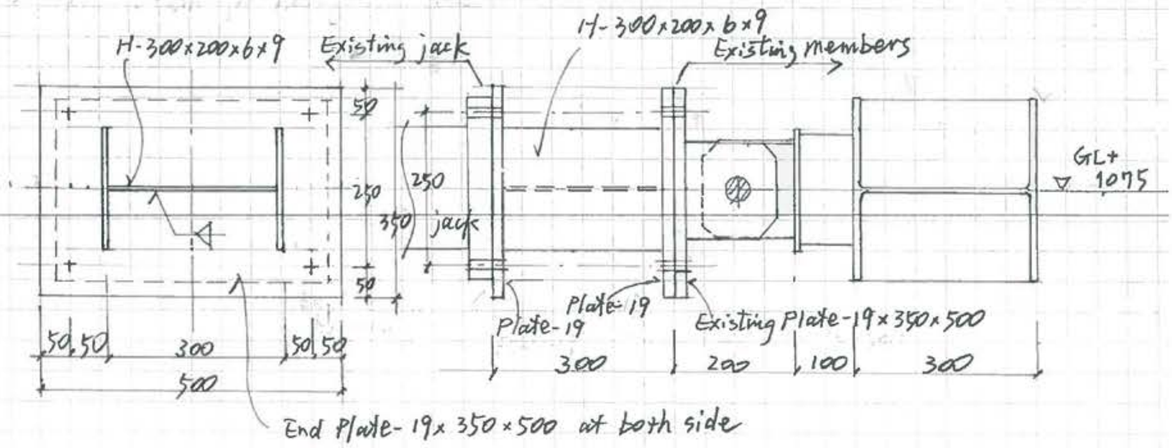
3) Structural steel (following 4 drawings, unit; mm)



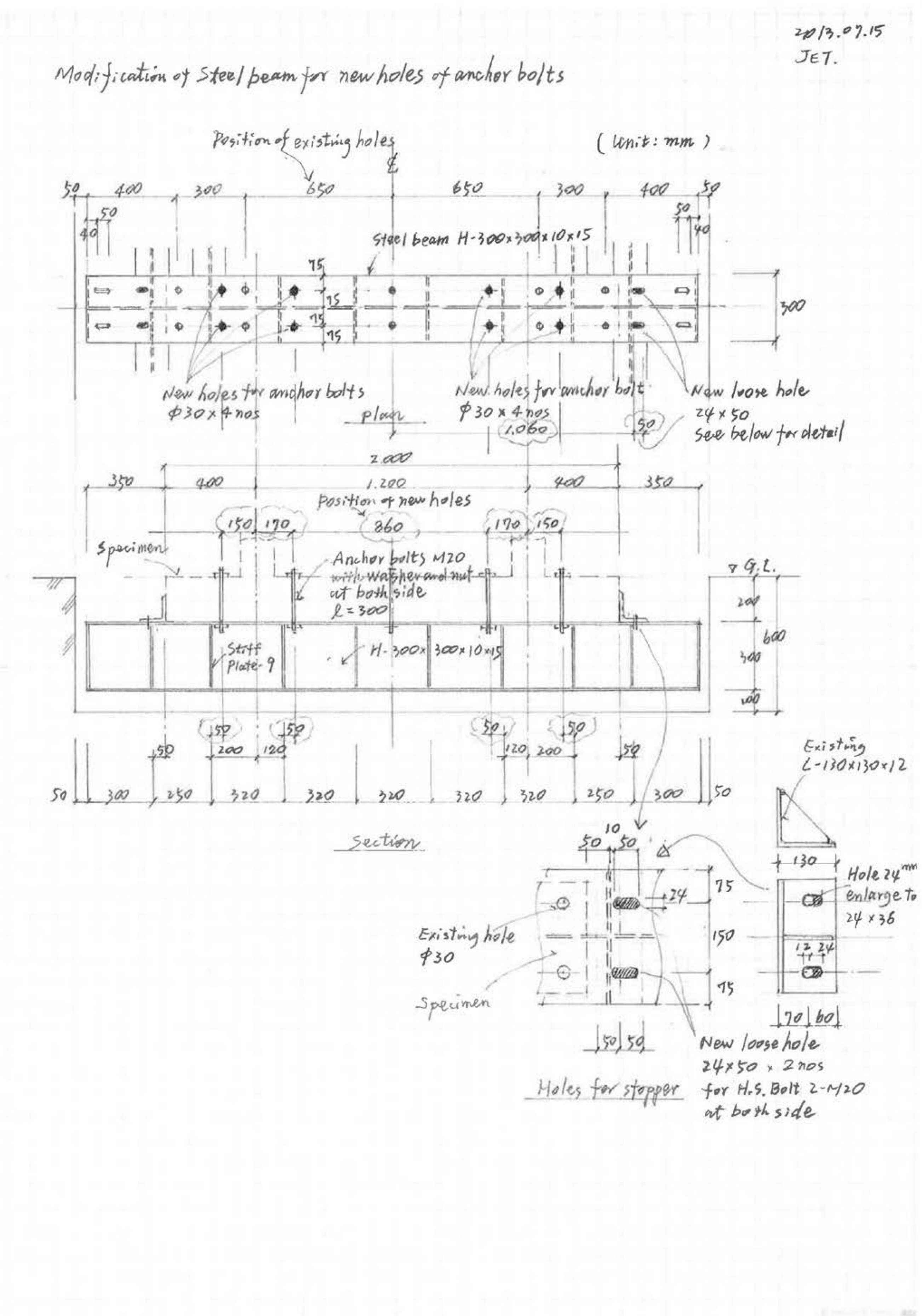
2013. 6. 15

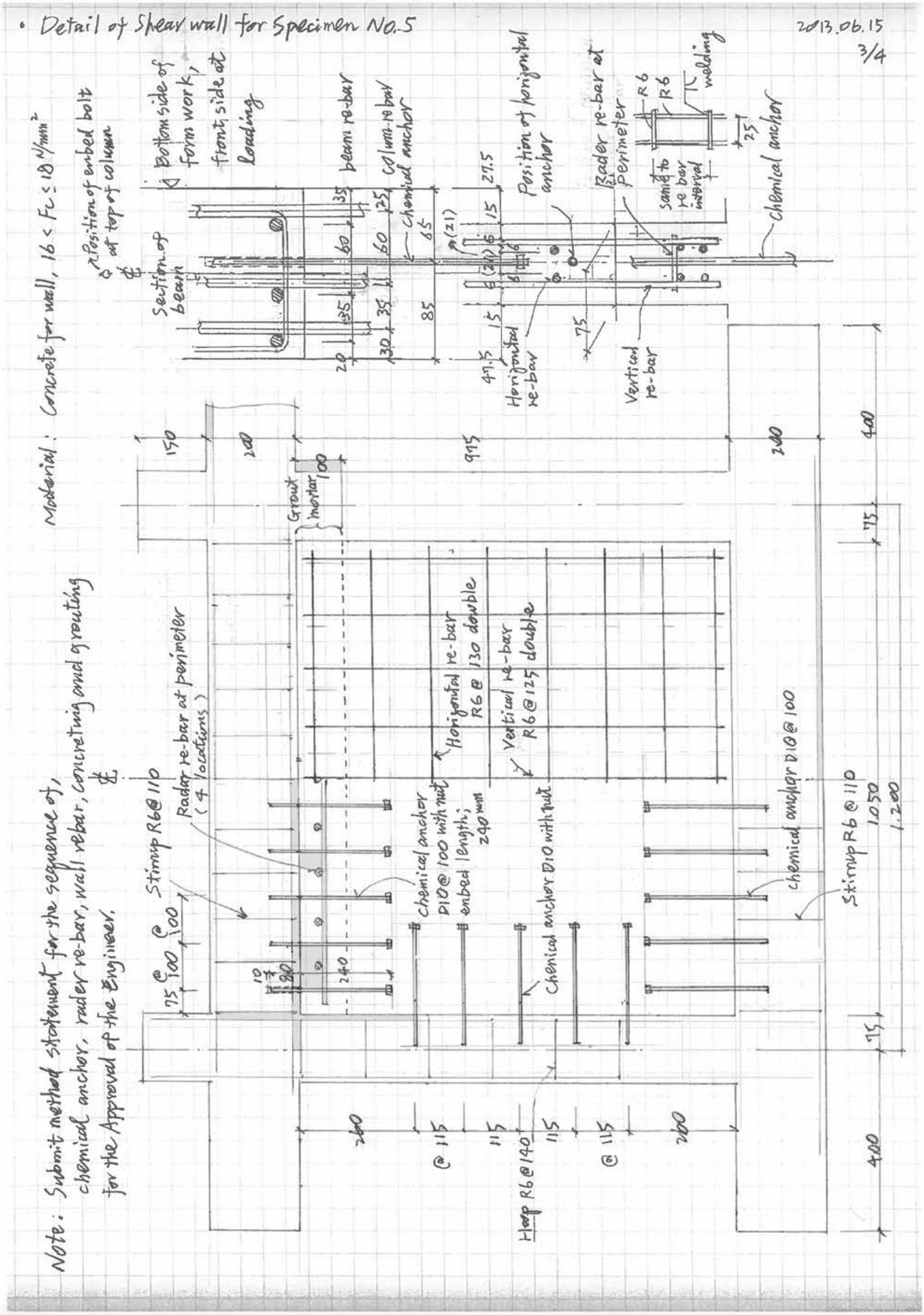
2/4

• Steel beam for horizontal loading × 2 pieces

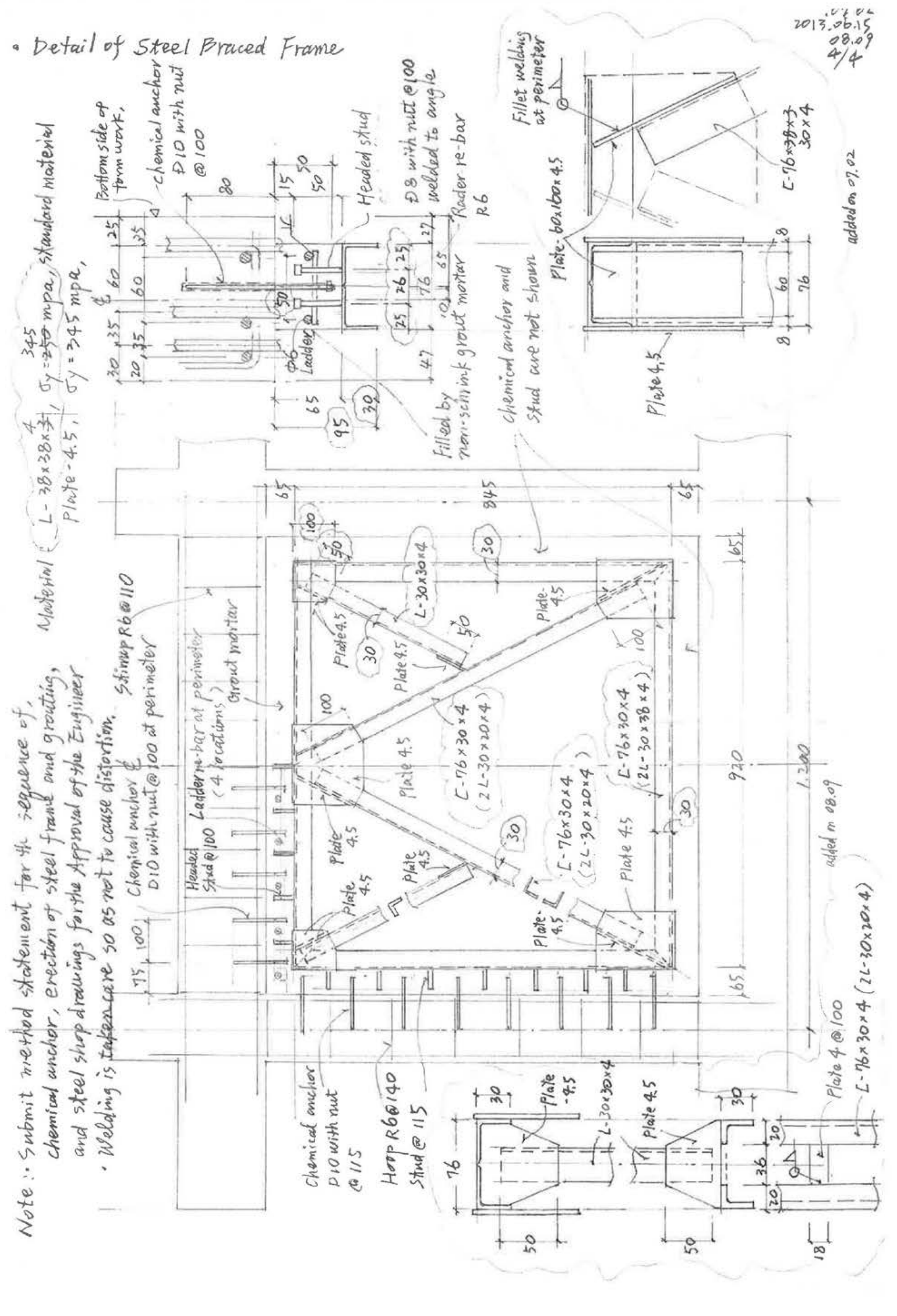


Bolt size is same to existing bolt for fixing baseplate of hydraulic jack.


2013.07.15
JET.
Modification of Steel beam for new holes of anchor bolts
Position of existing holes
(Unit: mm)
Steel beam H-300x300x10x15
New holes for anchor bolts
φ30 x 4 nos
plan
New holes for anchor bolt
φ30 x 4 nos
New loose hole
24 x 50
see below for detail
Position of new holes
Specimen
Anchor bolts M20
at both side
ℓ = 300
G.L.
Stiff Plate-9
H-300x300x10x15
Section
Existing hole
φ30
Specimen
Existing
L-130x130x12
Hole 24mm
enlarge to
24 x 36
New loose hole
24x50 x 2nos
for H.S. Bolt 2-M20
at both side
Holes for stopper



• Detail of Shear wall for Specimen No.5
2013.06.15
3/4
Note: Submit method statement for the sequence of, chemical anchor, rader re-bar, wall rebar, concreting and grouting for the Approval of the Engineer.
Material: Concrete for wall, 16 ≤ Fc ≤ 18 N/mm²
Position of embed bolt at top of column
Section of beam
Bottom side of form work, front side at loading
beam re-bar
column re-bar
chemical anchor
Position of horizontal anchor
Rader re-bar at perimeter
R6
welding
same to re bar interval
chemical anchor
Horizontal re-bar
Vertical re-bar
Grout mortar
Stirrup R6@110
Radar re-bar at perimeter (4 locations)
Horizontal re-bar R6 @ 130 double
Vertical re-bar R6@125 double
chemical anchor D10@100 with nut embed length; 240 mm
Chemical anchor D10 with nut
Hoop R6@140
chemical anchor D10@100
Stirrup R6 @ 110
1,050
1,200



• Detail of Steel Braced Frame
2013.06.15
08.09
4/4
Note :· Submit method statement for the sequence of, chemical anchor, erection of steel frame and grouting, and steel shop drawings for the Approval of the Engineer
· Welding is taken care so as not to cause distortion.
Material : L-38×38×4, σy=345 mpa, standard material
Plate-4.5, σy=345 mpa,
Bottom side of form work,
chemical anchor D10 with nut @100
Headed stud
D8 with nut @100 welded to angle
Rader re-bar R6
Filled by non-shrink grout mortar
chemical anchor and stud are not shown
Fillet welding at perimeter
Plate-60x100x4.5
Plate 4.5
added on 07.02
Stirrup R6@110
Chemical anchor D10 with nut @100 at perimeter
Headed Stud @100
Ladder re-bar at perimeter (4 locations)
Grout mortar
L-30x30x4
C-76×30×4 (2L-30×20×4)
C-76×30×4 (2L-30×38×4)
added on 08.09
Chemical anchor D10 with nut @115
Hoop R6@140
Stud @115
Plate 4 @100
C-76×30×4 (2L-30×20×4)
845
920
1,200

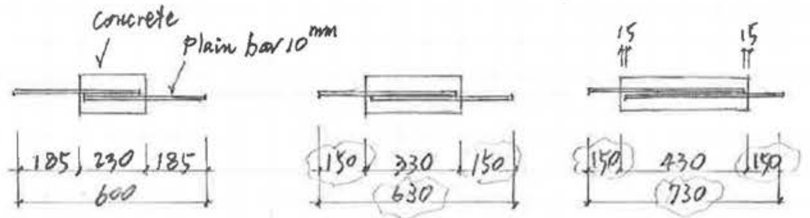
4) Supplemental drawing

07.02
2013.06.29
revised 07.15

Structural Test - Supplement

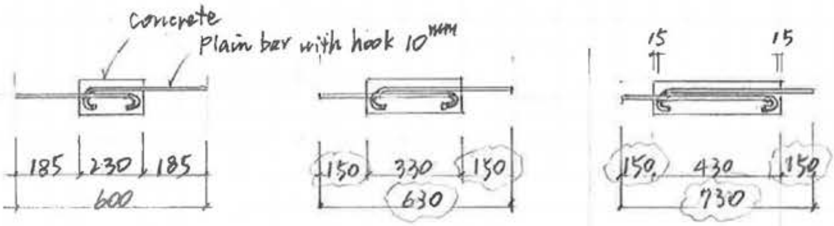
B.Q. Item B-7 Tensile Test of Re-bar for Concrete Bond Stress.

a) 3 pieces for bond stress, concrete size 75mm x 75mm x length (shown below)



(1) Lap length 200mm, (2) lap length 300mm (3) Lap length 400mm

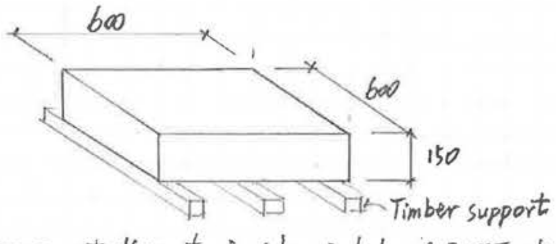
b) 3 pieces with hook, concrete size 75mm x 75mm x length (shown below)



(1) Length 200mm (2) Length 300mm (3) Length 400mm

Note: Detail might be changed subject to the discussion with the lab. of BUET.

B.Q. Item B-8 Plain Concrete block with size of 600mm x 600mm x 150mm (height)



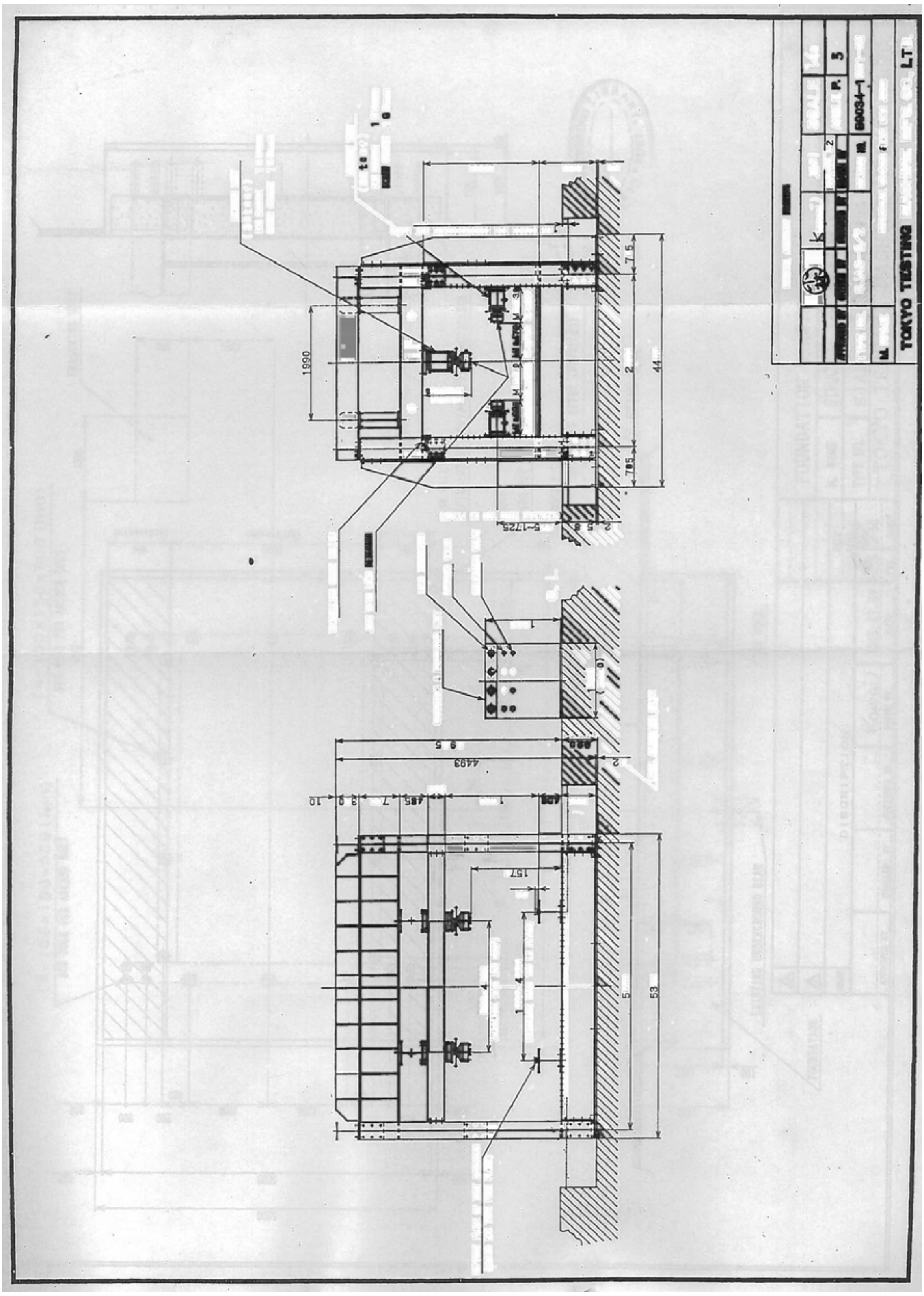
Including, 1) transportation to inside of lab. of BUET for core drilling.

2) supporting work for core drilling by PWD engineers (ϕ100x3, ϕ50x3)

3) demolishing after coredrilling

Note: Concrete shall be cast on the same day of structural test specimen.

5) Existing Reaction Frame with Hydraulic Jacks and Load Cell, BUET



Attachment 3: Scope of Services 2013/07/14

		PWD, JET	**BUET**	**DUET**
1	Detail plan of experiment, design of additional steel members, and specimens	○	Review and confirmation	Review and confirmation
2	Fabrication of steel member	○ (sub contractor)		
3	Trial mix of concrete	○ (sub contractor)		
4	Tensile test of re-bar and steel plate, including stress strain curve	○ (coordination)	○ (application from sub contractor)	
5	Bond test of re-bar	○ (coordination)	○ (application from sub contractor)	
6	Adjustment of data-logger	○ (coordination)	○ (exercise by re-bar tensile test)	
7	Pasting strain gauge on re-bar and steel braced frame	○ (Supply of strain gauges)	○ (Paste work of strain gauge)	
8	Formwork, re-bar, concreting, curing of specimen,	○ (sub contractor)		
9	Calibration of load cell		○	
10	Installation of additional steel members and adjustment of reaction frame	○ (sub contractor)	○ (coordination, if required)	
11	Installation and dismantle of test specimen	○ (sub contractor)		
12	Cable connection and setting DG and DT	○ (coordination, providing DT and DG)	○ (main)	○ (support)
13	Loading and measurement	○ (coordination and provide labors)	○ (main)	○ (support)
14	Preparation of load deflection curve by load-cell and DT, and load-meter and DG	○ (coordination)	○ (main)Note 2	○ (support)
15	Photos of specimen	○ (coordination)	○ (sub)	○(main)
16	Compilation of report	○ (main)	○ (support)	○ (support)

Note: 1) DT means Displacement Transducer, and DG means Dial Gauge.

2) Load deflection curve of each specimen will be prepared on the next of the experiment.

Attachment 4: Time Schedule

Preliminary test schedule 2013/8/13

2013: Apr. – Dec.; 2014: Jan. – Feb.

No.	Activity	
1	Plan of experiment, design & specification of additional steel members and specimen	
2	Document for subcontract	
3	Quotation & subcontract	
4	Trial mix of concrete	Curing
5	Re-bar tensile test	
6	Exercise of data-logger for strain gauge of re-bar test	
7	Steel shop drawing	Approval
8	Fabrication of steel members	
9	Test of bond and anchor of re-bar	
10	Preparation of site space with roof for specimen	
11	Formwork, re-bar with strain guage and concreting of 7 test specimen	Curing
12	Concreting for core sampling	
13	Brick work for specimen	Curing
14	Retorfit work of specimen by steel bracing and RC shear wall	Curing
14	Adjustment of steel members at the site	
16	Adjustment of data-logger and load cell	
17	Loading and measurement for 6 specimen	
18	Report of test result	
19	Review and comment	
20	Final report	

Note:

Appendix 1: Photos (3 sheets),
1st Experiment (2012)



Reaction frame (Painting and lighting) Specimen Control panel

Pinned connection

Built-in pinned connection


Vertical and horizontal hydraulic jack



Data-ligger (BUET)

Displacement transducer and dial gauge

Bridge box for strain gauge

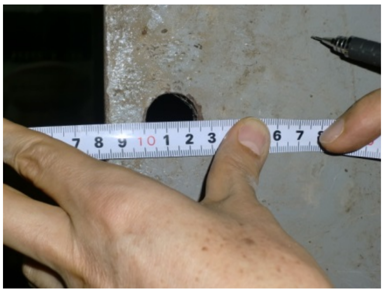


Detail of load cell and specimen

Transportation of specimen by 2 ton capacity lift

Laboratory of Civil Engineering Department, BUET

Existing Column



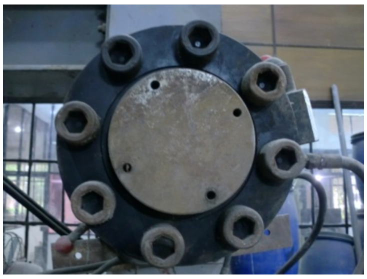
Width 300mm, depth 400mm, position of bolt hole 30mm from the edge, hole diameter 22mm to 24mm, hole vertical interval 100mm.   Bolt hole, ground floor plus 225 @100 up to 1,725.

Flange thickness 20mm, hole size, approx. 22 to 24mm

Vertical jacks



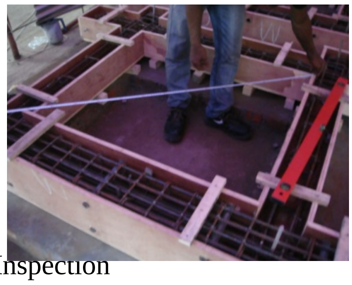




Baseplate of the jack, approx. 300mm x 450mm x 55mm (thickness), interval of bolt holes, approx. 250mm and 400mm, bolt size approx.22mm

Horizontal jack   Edge of the Load cell

Fabrication of the test specimen of 2nd experiment (2013)


Assembly of re-bar Inspection Re-bar arrangement



Bonding of strain gauge and water proofing coating

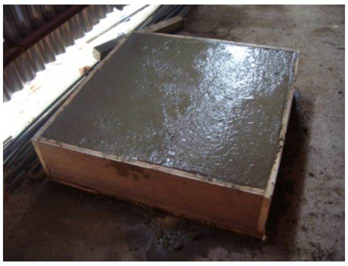
Concreting




Weight meter Cement, brick chip and cement Fresh concrete Slump test



Concreting and surface finishing



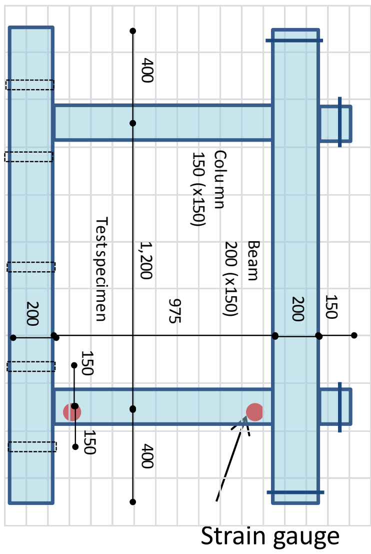
Plain concrete for core sampling Specimen for bond test

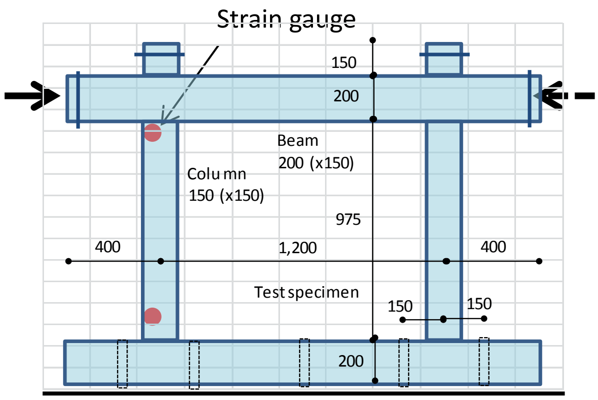
Appendix 2

1. Explanation of Front side and Rear side of a Specimen

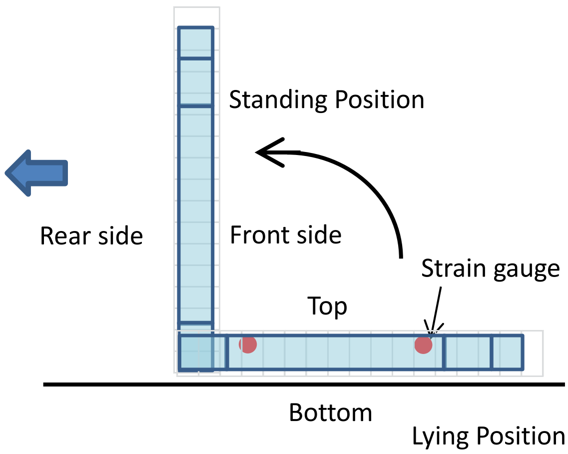
The front side of standing position of a specimen for loading is the bottom side of lying position for concreting.

Concreting with lying position





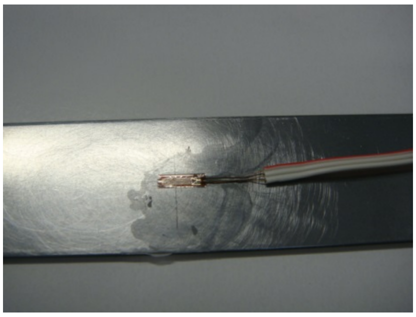
Front side of Standing Position for loading

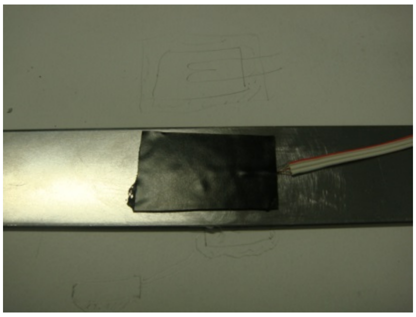


2. Bonding Strain Gauges

Bonding strain gauge and water protection coating are shown below.

Refer to “Strain gauge bonding procedure” of the Kyowa’s brochure, for the procedure (1) to (8).





8. Bonding strain gauge with polyethylene sheet by thumb for 60 seconds

9. Remove excessive adhesive by sandpaper if any, and putting VM tape without air.

10. Putting AK-22 clay under the lead-wire

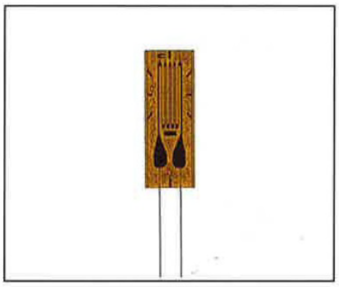
11. Putting AK-22 clay for overall

12. Provide vinyl tape to protect AK-22 and strain gauge during concreting.

Strain Gage Bonding Procedure

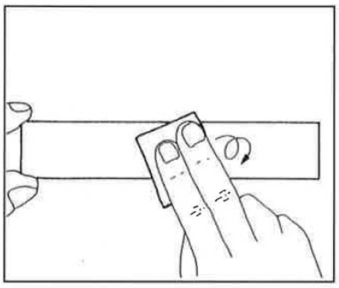
The strain-gage bonding method differs depending on the type of the strain gage, the applied adhesive and operating environment. Here, for the purpose of strain measurement at normal temperatures in a room, we show how to bond a typical leadwire-equipped KFG gage to a mild steel specimen using CC-33A quick-curing cyanoacrylate adhesive.

(1) Select strain gage



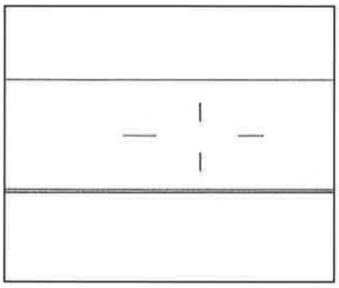
Select the strain gage model and gage length which meet the requirements of the measuring object and purpose. For the linear expansion coefficient of the gage applicable to the measuring object, refer to page 13. Select the most suitable one from the 11 choices.

(2) Remove dust and paint.



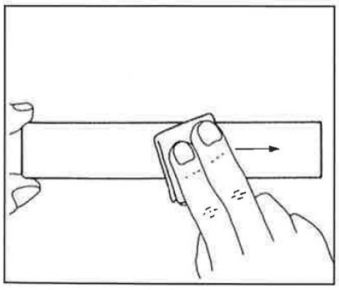
Using a sand cloth (#200 to 300), polish the strain-gage bonding site over a wider area than the strain-gage size.
Wipe off paint, rust and plating, if any, with a grinder or sand blast before polishing.

(3) Decide bonding position.



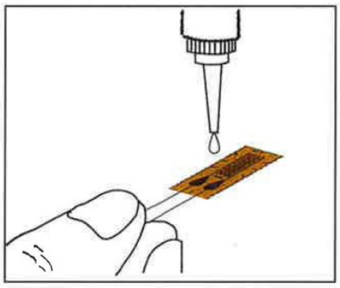
Using a #2 pencil or a marking-off pin, mark the measuring site in the strain direction. When using a marking-off pin, take care not to deeply scratch the strain-gage bonding surface.

(4) Remove grease from bonding surface and clean.



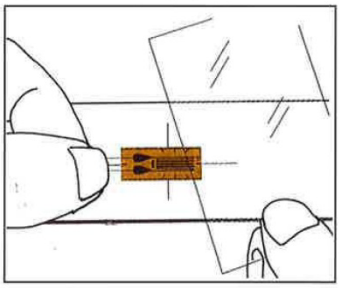
Using an industrial tissue paper (SILBON paper) dipped in acetone, clean the strain-gage bonding site. Strongly wipe the surface in a single direction to collect dust and then remove by wiping in the same direction. Reciprocal wiping causes dust to move back and forth and does not ensure cleaning.

(5) Apply adhesive.



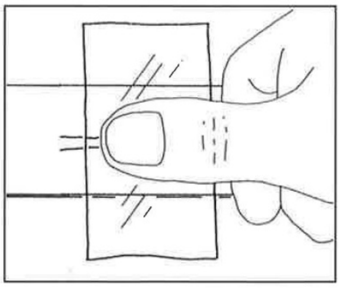
Ascertain the back and front of the strain gage. Apply a drop of CC-33A adhesive to the back of the strain gage. Do not spread the adhesive. If spreading occurs, curing is adversely accelerated, thereby lowering the adhesive strength.

(6) Bond strain gage to measuring site.



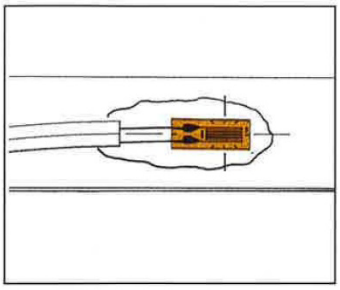
After applying a drop of the adhesive, put the strain gage on the measuring site while lining up the center marks with the marking-off lines.

(7) Press strain gage.



Cover the strain gage with the accessory polyethylene sheet and press it over the sheet with a thumb.
Quickly perform steps (5) to (7) as a series of actions. Once the strain gage is placed on the bonding site, do not lift it to adjust the position. The adhesive strength will be extremely lowered.

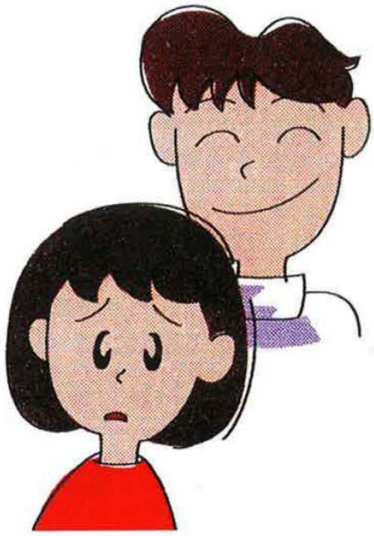
(8) Complete bonding work.



After pressing the strain gage with a thumb for one minute or so, remove the polyethylene sheet and make sure the strain gage is securely bonded. The above steps complete the bonding work. However, good measurement results are available after 60 minutes of complete curing of the adhesive.

- 15 -

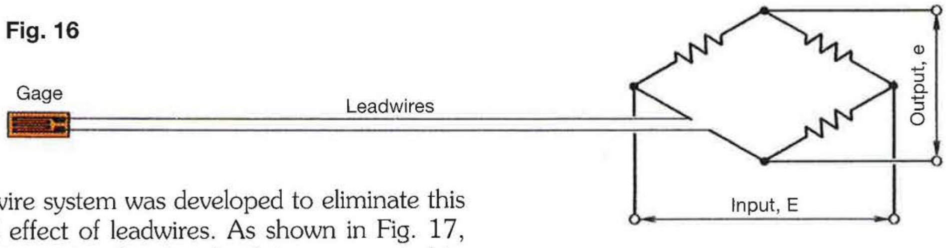
Leadwire Temperature Compensation



The use of the self-temperature-compensation gage (SELCOM gage) eliminates the thermal effect from the gage output. But leadwires between the gage and the strain-gage bridge are also affected by ambient temperature. This problem too should be solved.

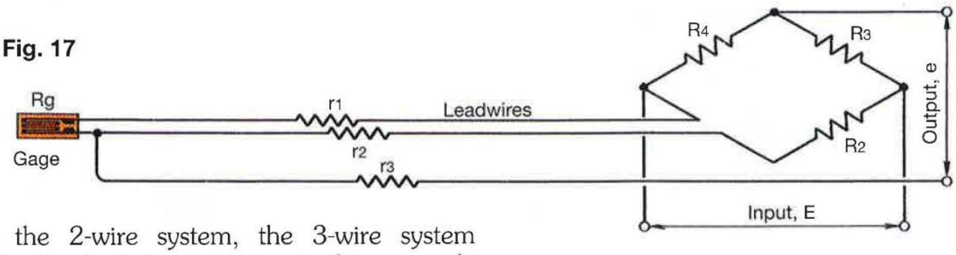
With the 1-gage 2-wire system shown in Fig. 16, the resistance of each leadwire is inserted in series to the gage, and thus leadwires do not generate any thermal problem if they are short. But if they are long, leadwires adversely affect measurement. The copper used for leadwires has a temperature coefficient of resistance of 3.93 $\times 10^{-3}$/°C. For example, if leadwires 0.3mm^2 and 0.062 Ω/m each are laid to 10 m length (reciprocating distance: 20 m), a temperature increase by 1°C produces an output of 20 $\times 10^{-6}$ strain when referred to a strain quantity.

Fig. 16



The 3-wire system was developed to eliminate this thermal effect of leadwires. As shown in Fig. 17, the 3-wire system has two leadwires connected to one of the gage leads and one leadwire connected to the other.

Fig. 17



Unlike the 2-wire system, the 3-wire system distributes the leadwire resistance to the gage side of the bridge and to the adjacent side. In Fig. 17, the leadwire resistance r_1 enters in series to Rg and the leadwire resistance r_2 enters in series to R_2. That is, the leadwire resistance is distributed to adjacent sides of the bridge. The leadwire resistance r_3 is connected to the outside (output side) of the bridge, and thus it produces virtually no effect on measurement.

- 14 -

2.3 Load-deflection curve

Loading date of each specimen and incidents occurred are shown as follows;

No.	Date	Remarks (observation during the loading)
3	28 October 2013	Broken of screw stroke of right hydraulic jack was observed. Strain gauge no.5, 7 and 12 were not working. DT/DG of right lower position dropped after 2nd cycle.
4	3 November	Strain gauge no.10 and 12 were not working.
1	5, 6 November	Strain gauge no.12 was not working. Dial gauge at right lower position was not working well.
2	9 November	Filler plates were inserted at the boundary of RC beam and steel foundation beam. Strain gauge no.10 and 12 were not working. After the cycle 6, upper reaction steel beam moved horizontally and was corrected.
5	12, 16 November	Filler plates were inserted at the boundary of RC beam and steel foundation beam to fill the gap. Loading suspended because hydraulic jack capacity 23ton, and wall with size of 200mmx250mm was provided at wall on 13 November. Loading was continued on 16 November.
6	18 November	Strain gauge No.1 and no.2 are missing. No.12 is not working. After the 3rd cycle, left lower DT/DT has some error due to a needle on a crack of concrete surface.

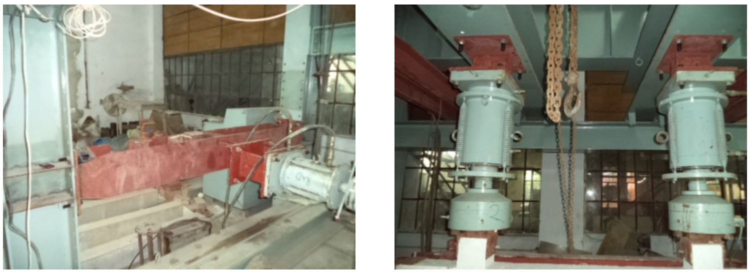
Note: 1. “Hartal (political demonstration)” was executed during the period of load-measurement period,

1) 27 October ~ 29 October (60hours)
2) 4 November ~ 6 November (60 hours)
3) 10 November ~ 13 November (72 hours)

2. BUET admission test related, 31 October ~ 2 November

General

Reaction frame

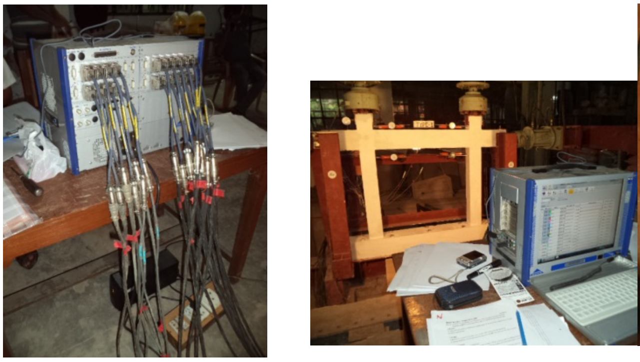


Hydraulic jack and load cell

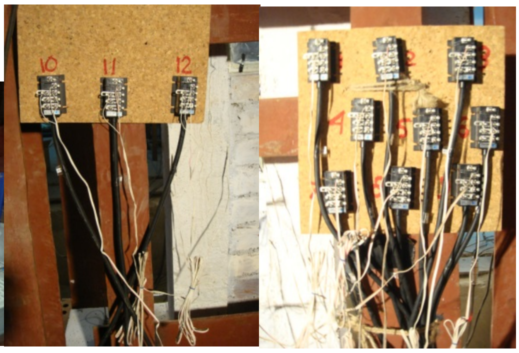
Steel foundation beam and measurement frame

Filler plate for reaction beam

Setting of Displacement transducer and Dial gauge



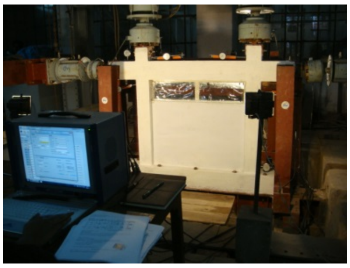
Data logger and connecting cables

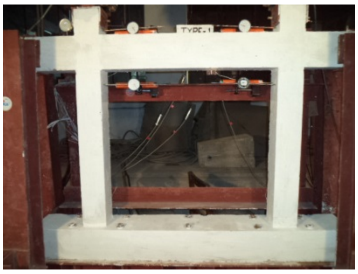


bridge box for strain gauge



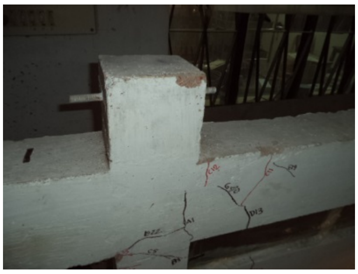
Setting of Displacement Transducer and Dial Gauge





Setting initial value for data logger





Filler plate at bottom og beam loading Damage of column top (No.3) was ninor after the test.

DT at side of bottom beam for No.5

Result of specimen No.1

R=0 (R; story deflection angle = story deflection/ story height)

(Providing axial force)

Axial force of 16 ton which is axial force (N/bdFc) ratio 68% was imposed.

When axial force was imposed with step of 4, 8, and 12ton, diagonal crack occurred at left side of top and bottom beam, then load was increased to 14 and 16 ton. Possible reason of crack is that there is a gap between bottom beam and foundation steel beam with 1~2mm. Because vertical deflection of left side of upper beam showed 3.6mm by DG, which is very big, when vertical load was imposed.

R<1/400 (δ < 2.94mm), 1st and 2nd Cycle,

Initial stiffness was 1.25t/mm (= 1ton/0.8mm).

Max. load: positive 1st, 2.3ton. 2nd, 2.6ton, negative 1st, 2.7 ton, 2nd 3.0ton

No crack was observed on columns.

Diagonal cracks occurred on top and bottom of beam.

R<1/200 (δ < 5.88mm), 3rd and 4th cycle,

Max. load: positive 3st, 3.7ton. 4th, 3.6ton, negative 3rd, 4.0ton, 4th 3.7ton

Diagonal crack was observed on top of left column.

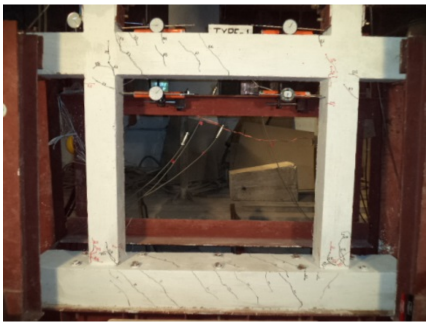
R<1/100 (δ < 11.75m), 5th and 6th cycle

Max. load: positive 5th, 4.5ton. 6th, 4.3 ton, negative 5st, 4.0ton, 6th 3.5 ton

Flexural cracks occurred at top and bottom of columns.

Vertical cracks also occurred at bottom of columns.

Diagonal crack occurred at top of right column.

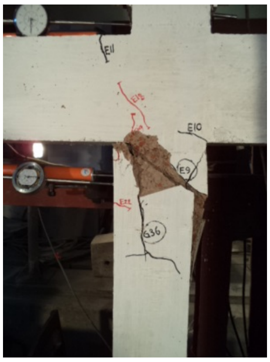


R<1/50 (δ <23.5mm) , 7th cycle

Max. load: 7th positive, 4.2ton to 3.5ton.

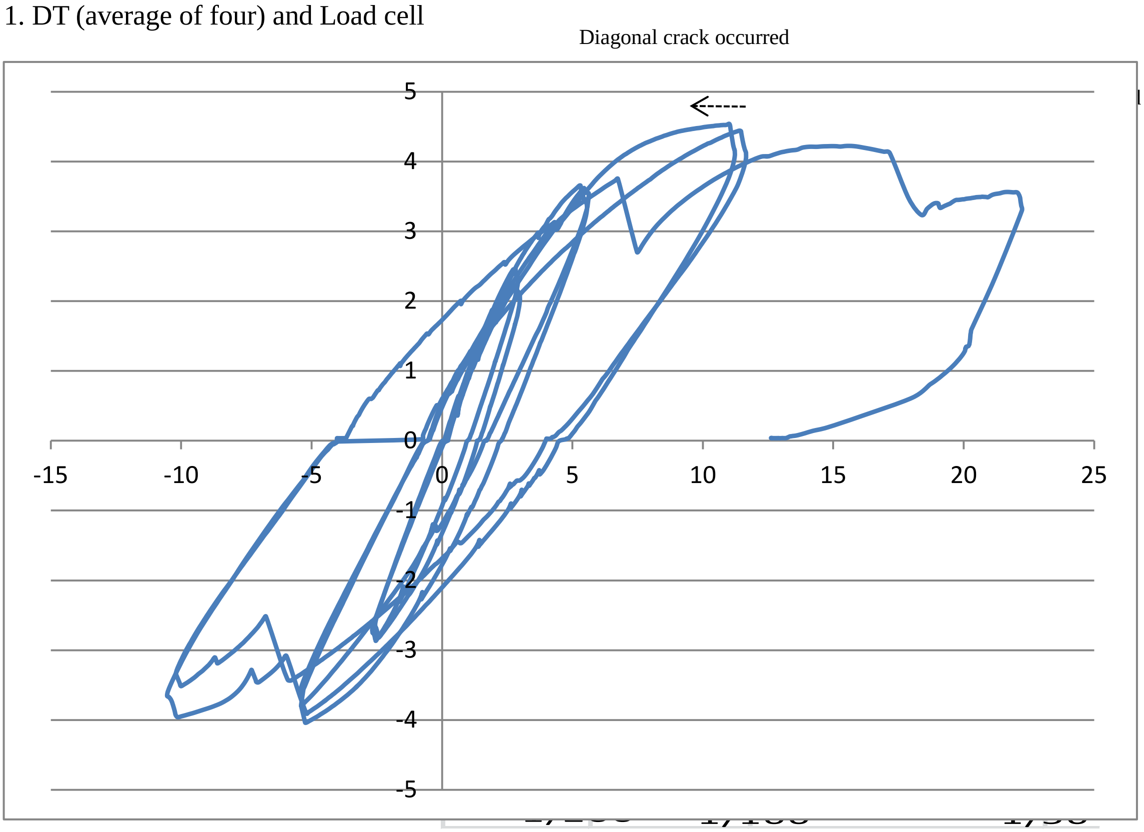
7th positive , 3.5 ton at 23.5mm, shear failure at the top of right column occurred. Horizontal load reduced from 3.5 ton to 2.0 to at 25.7mm, and 1.7 ton at 26.0mm. Vertical

load reduced from 16 ton to 3 ton only. The column cannot support vertical load at R=1/50. The load was released.

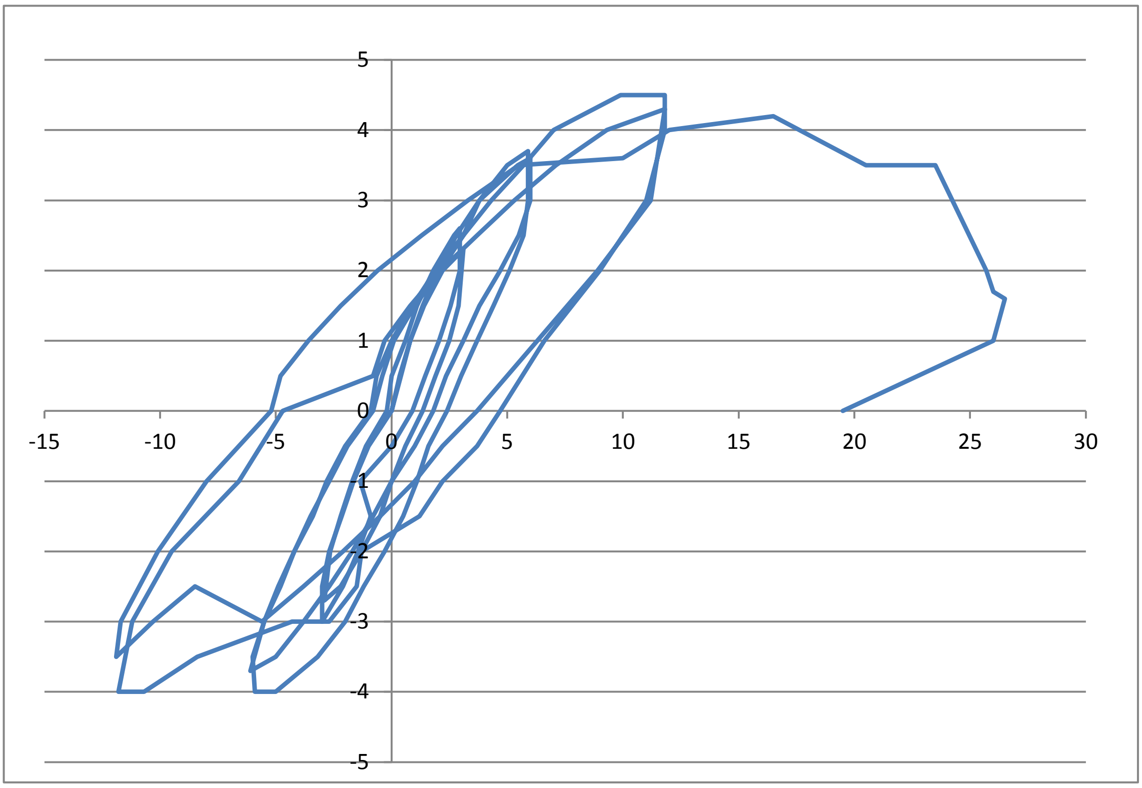


Load-deflection curve, No.1

1. DT (average of four) and Load cell



2. Dial Gauge (Left top D.G.) and load meter



Result of specimen No.2 2013/11/09 (Sat.)

Axial load, 16 ton.

(left) Filler plate of 1mm thickness was inserted between RC beam and steel foundation. A inclination was observed on top of steel foundation beam. (right) Reaction beam was slide at 6th cycle. Rectification was done, and vertical load and horizontal load was provided again.

Behavior;

Axial load, with step of 4, 8, 12, 16 ton was provided. Out of plain movement of columns was observed.

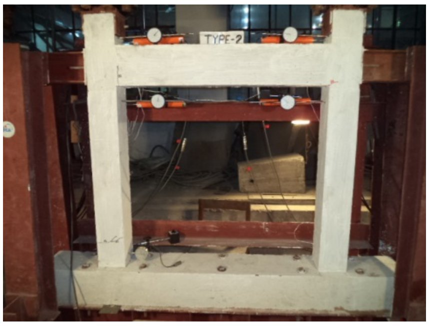
R<1/400 (δ < 2.94mm), 1st and 2nd Cycle,

Initial stiffness was 1.85t/mm (= 1ton/0.55m).

Max. load: positive 1st, 2.0 ton. 2nd, 2.5ton, negative 1st, 3.0 ton, 2nd 3.0ton

Slip with 1.2mm was caused at 2.0 ton, 1st cycle positive loading.

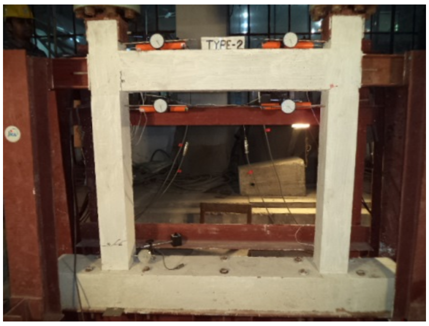
Crack was observed at front side of bottom of left column.



R<1/200 (δ < 5.88mm), 3rd and 4th cycle,

Max. load: positive 3rd, 3.3ton. 4th, 3.2ton, negative 3rd, 4.0ton, 4th 3.8ton

No clear change was observed.



R<1/100 (δ < 11.75m), 5th and 6th cycle

Max. load: positive 5th, 3.9ton. 6th, 3.5 ton, negative 5st, 5.0ton, 6th 4.0 ton

Vertical crack extended at both panel zone, and strength dropped from 3.5 ton (7.8mm) to 3.0 ton (12.4mm).

Flexural cracks occurred at bottom of columns.

R<1/50 (δ <23.5mm) , 7^{th} and 8^{th} cycle

Max. load: positive 7th, 4.0ton. 8th, 3.5 ton, negative 7th, 3.7 ton, 8^{th} 3.0 ton

Vertical and diagonal crack extended at both panel zone.

Cover concrete at bottom of column (especially rear side) was detached.

R<1/25 (δ <47.0mm) , 9^{th} cycle

Max.load; positive 3.5 ton (at -6.5mm), was reduced to 3.0ton (at +10mm), to 1.7 ton (at 20.1mm).

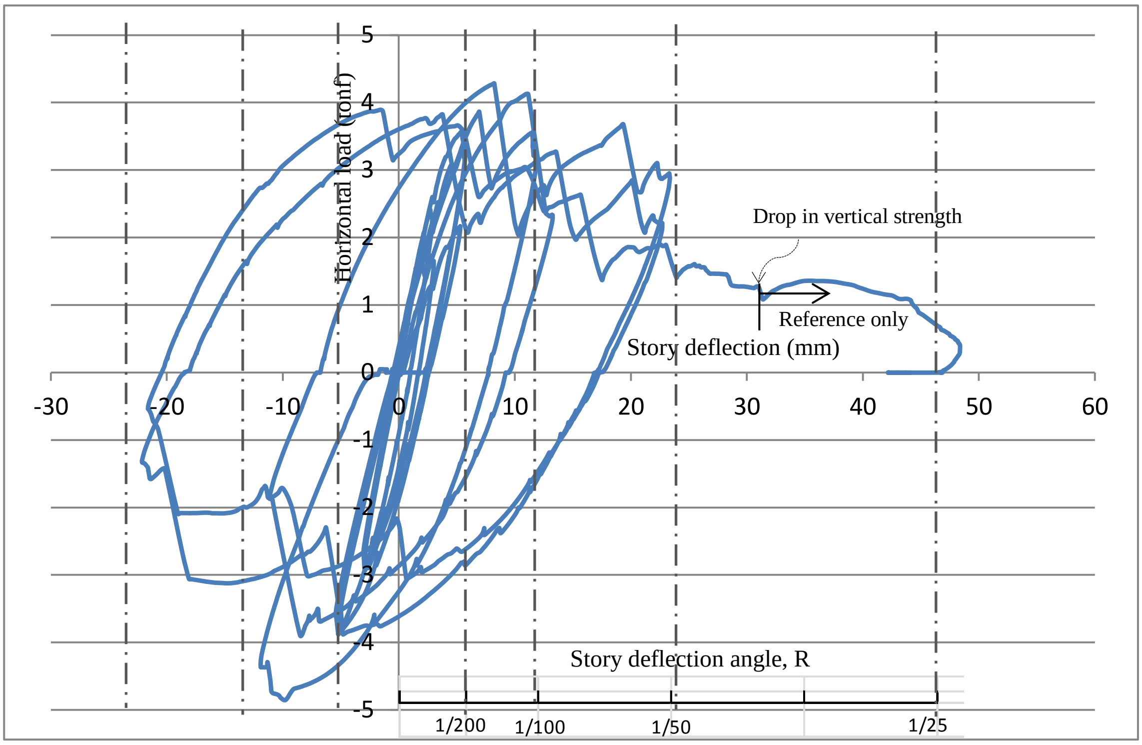
Vertical load was reduced from 16 to 8 ton at 30mm, and dropped to 4 ton further at 35mm. Bottom of column was failed.

Cracks of panel zone were extended.

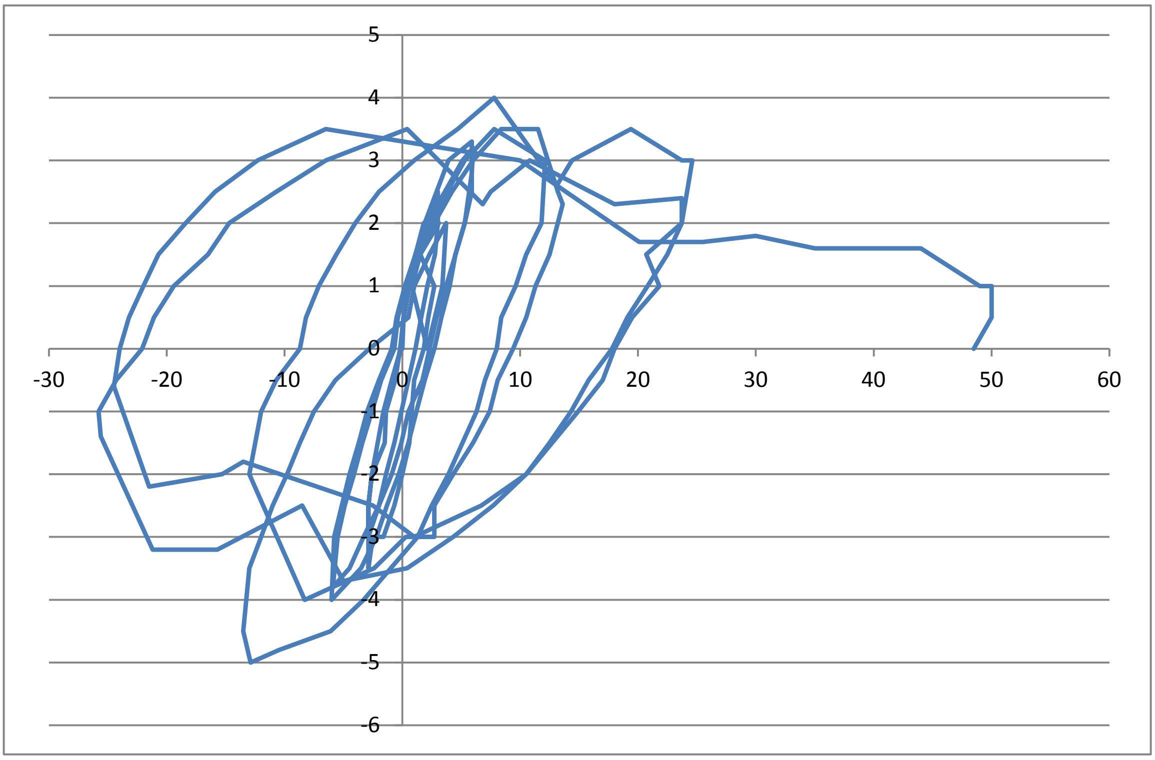
Structural Experiment by CNCRP

No.2 Load-deflection curve

1. DT (average of four) and Load cell



2. Dial Gauge (Left top D.G.) and load meter



Specimen, No.3

Date: 2013/10/28

Brick wall with thickness 60mm and with opening (with a window)

Observed collapse mode: shear failure of right side column.

R=0 (R; story deflection angle = story deflection/ story height)

(Providing axial force)

Axial force of 16 ton which is axial force (N/bdFc) ratio 60% was imposed.

When axial force was imposed with step of 4, 8, 12 and 16 ton, vertical crack occurred between left column and brick wall, and 1.65mm vertical displacement of column observed, while no clear cracks were observed at right column. Vertical deflection 1.65mm, which is 0.169% of column length, was observed.

R<1/400 (δ < 2.94mm), 1^{st} and 2^{nd} Cycle,

Initial stiffness was 6.67t/mm (= 1ton/0.15mm).

Max. load: positive 1^{st}, 6.2ton. 2^{nd}, 5.7ton, negative 1^{st}, 4.7 ton, 2^{nd} 4.3ton

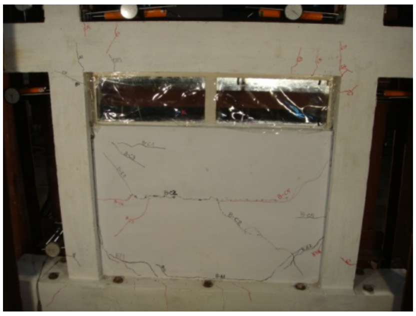
Flexural crack occurred at bottom of left and right column.

Cracks occurred for brick wall.

R<1/200 (δ < 5.88mm), 3^{rd} and 4^{th} cycle,

Max. load: positive 3^{st}, 7.7ton. 4th, 5.7ton, negative 3rd, 6.0 ton, 4th 4.5ton

Cracks extended for columns and brick walls



R<1/100 (δ < 11.75m), 5th and 6th cycle

Max. load: positive 5th, 7.6ton. 6th, 6.1ton, negative 5st, 5.6 ton, 6th 4.7ton

Diagonal and vertical crack extended on right column, crack occurred at 5th cycle.

Many flexural cracks occurred at left column.

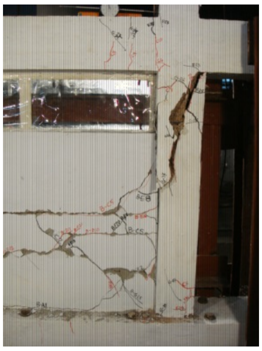
R<1/50 (δ <23.5mm) , 7th cycle

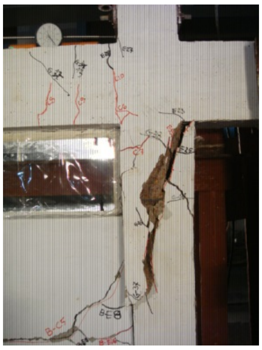
Max. load: 7th positive, 7.0ton and dropped to 5.8 ton at R=1/50. Glass was broken. 7th negative , 8 ton and shear failure of right column occurred at 8.7mm, dropped to 2.7 ton at 17.1mm, and load was released.

Glass was broken with the decrease of strength of 1.2ton.

Shear failure of right column occurred at negative loading.

Right column couldn't support vertical load and vertical load was released.



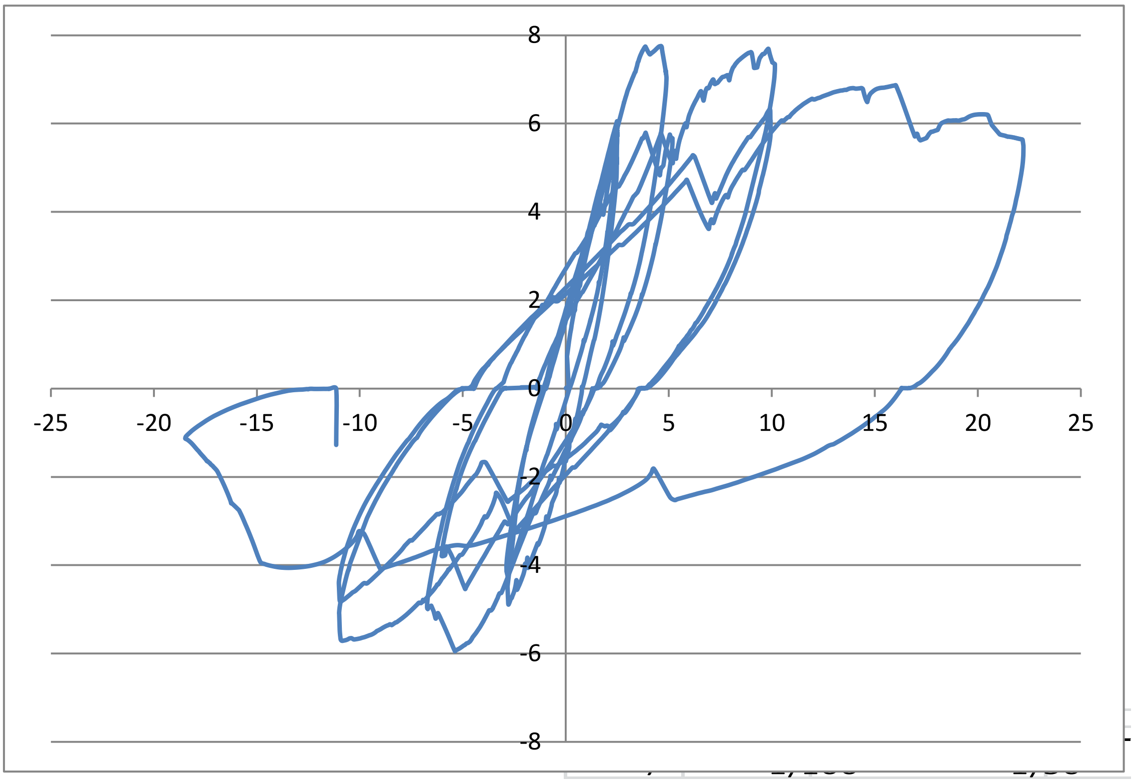


Shear failure of right column

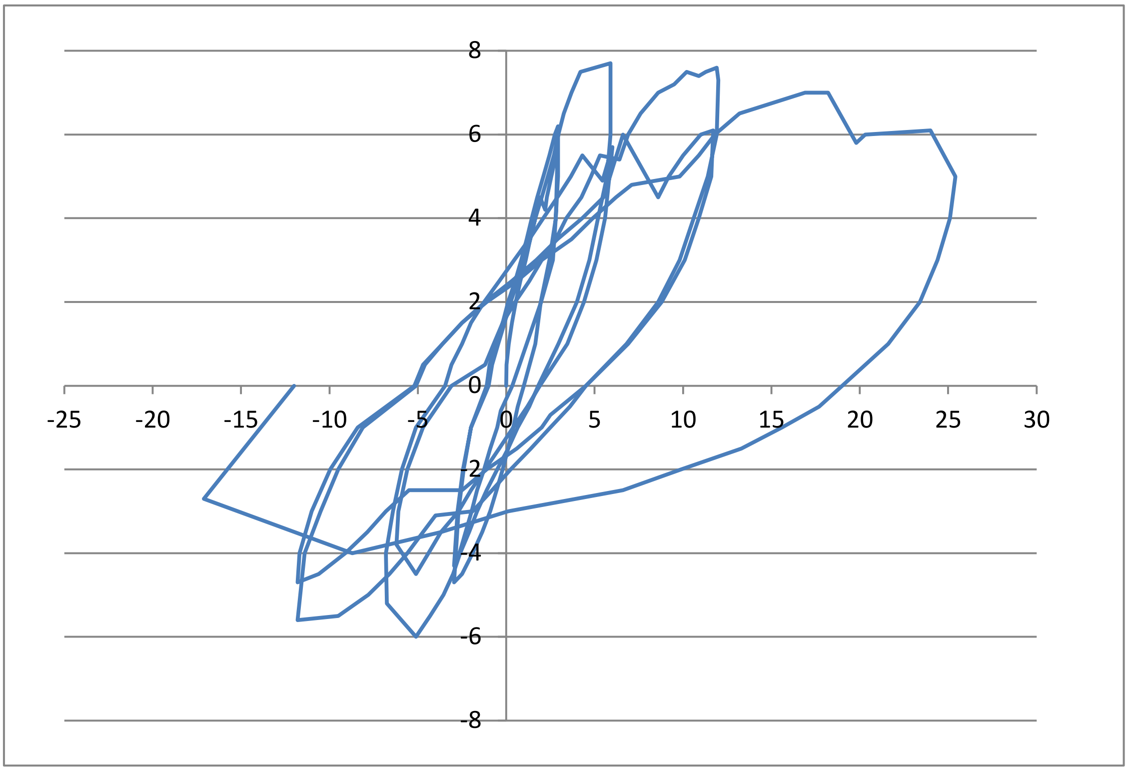
Out of plane movement of brick wall

No.3 Load-deflection curve

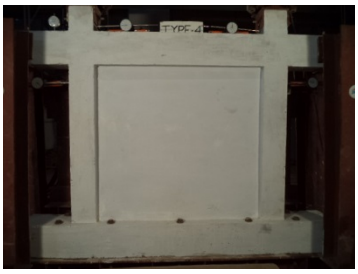
1. Displacement transducer (average of four DT) -Load cell



2. Dial Gauge (left upper)-- Load meter of Jack



<u>Specimen No.4</u> (brick wall with full-height of thickness 60mm, equivalent to actual size of 125mm, axial force ratio of column 0.68), loading on 3 November 2013.



R=0 (story deflection angle = story deflection/ story height), 0th cycle, vertical loading 16 ton, vertical deflection was 1.10mm, which is 0.0936% of storey height 1,175mm.

Vertical hair crack occurred at the boundary of left column and brick wall.

Note: According to the tensile test of re-bar 10mm, yield strain is 0.161% (=yield stress/young's modulus=350N/mm2/2.17x10^5N/mm2).

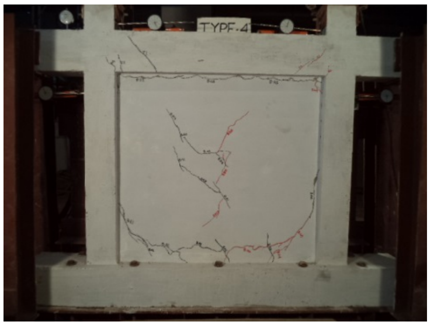
R = δ /h **< 1/400**, 1st and 2nd cycle, δ <2.94mm

Initial stiffness ; 2.0ton/0.3mm=6.67 ton/mm

Max. load: positive 1st, 8.2ton. 2nd, 8.5ton, negative 1st, 7.5 ton, 2nd 7.25ton

Diagonal crack occurred at upper beam.

Diagonal crack and horizontal cracks occurred at top and bottom of brick wall.

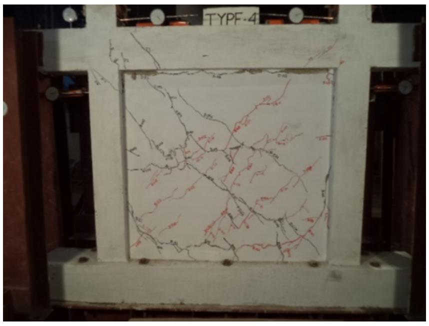


R<1/200 (δ < 5.88mm), 3rd and 4th cycle,

Max. load: positive 3rd, 11.0ton. 4th, 9.5ton, negative 3rd, 10.0 ton, 4th 1 9.75ton

Diagonal crack occurred at top of left column at 3rd cycle.

Cracks extended on brick wall.



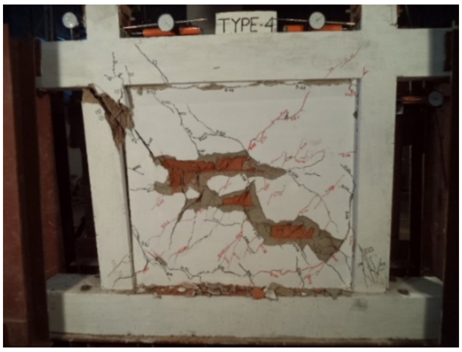
R<1/100 (δ <11.75mm), 5th cycle,

Shear failure occurred at let column at R=1/118 (10mm/1175mm) of positive loading.

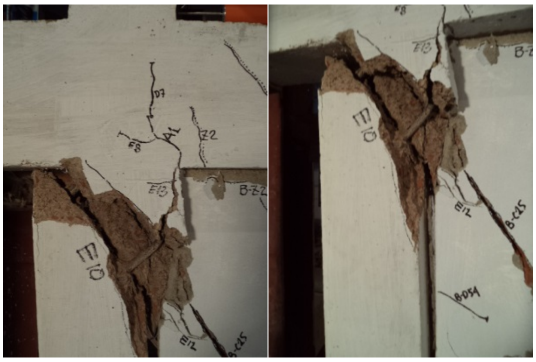
Horizontal load dropped suddenly from 10ton at R=1/118 to 6.5 ton at R=79 (14.8mm/1175mm), however maintained the vertical load.

Big diagonal crack extended on brick wall.

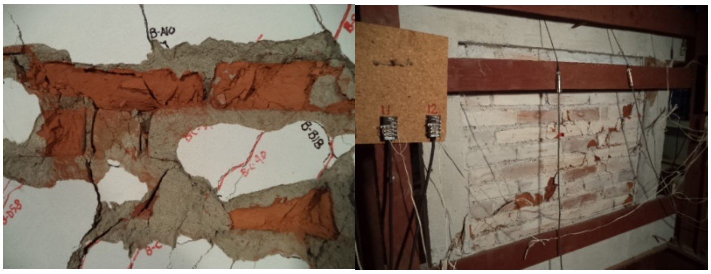
At negative loading, horizontal stiffness decreased from the point of -7.5ton/1.2mm and maximum load was -8 ton at -2.7mm/1175, and could not support vertical load. Vertical load dropped from -16 ton to -8 ton from the point of - 7.0ton/-7.5mm to 1.5ton/-12.5mm.



Shear failure of right column (front and rear side)



Shear failure of left column

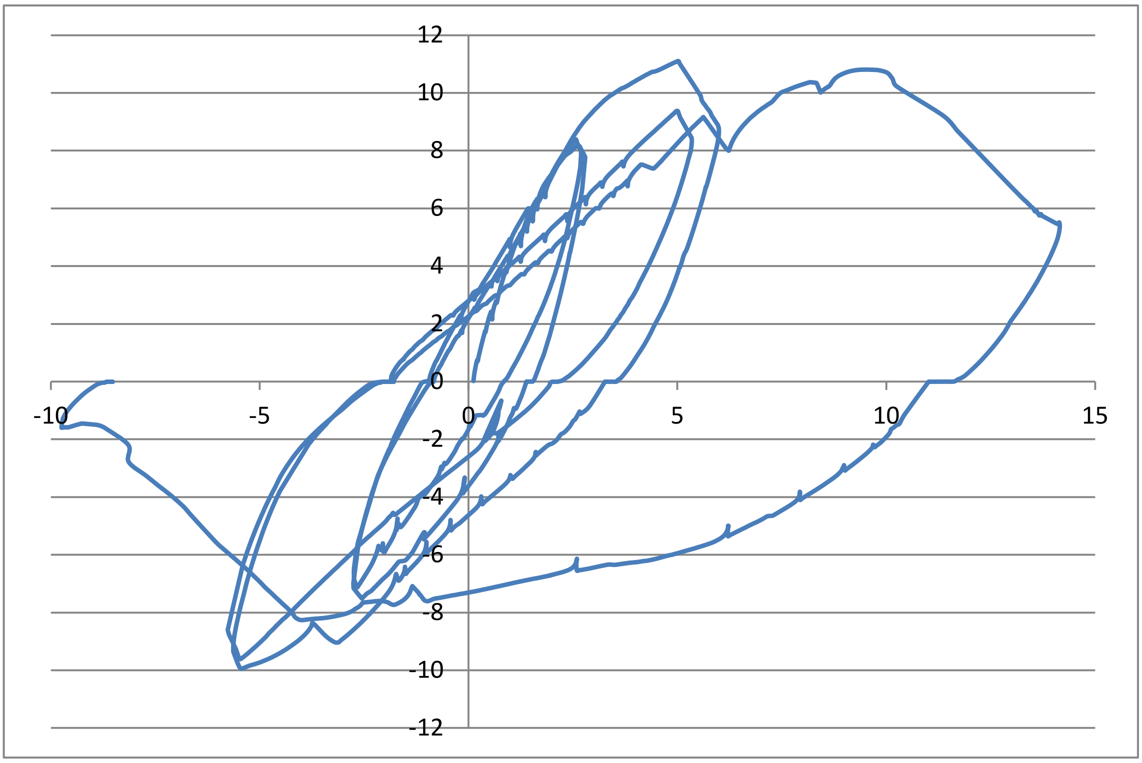


Brick wall (front and rear side)

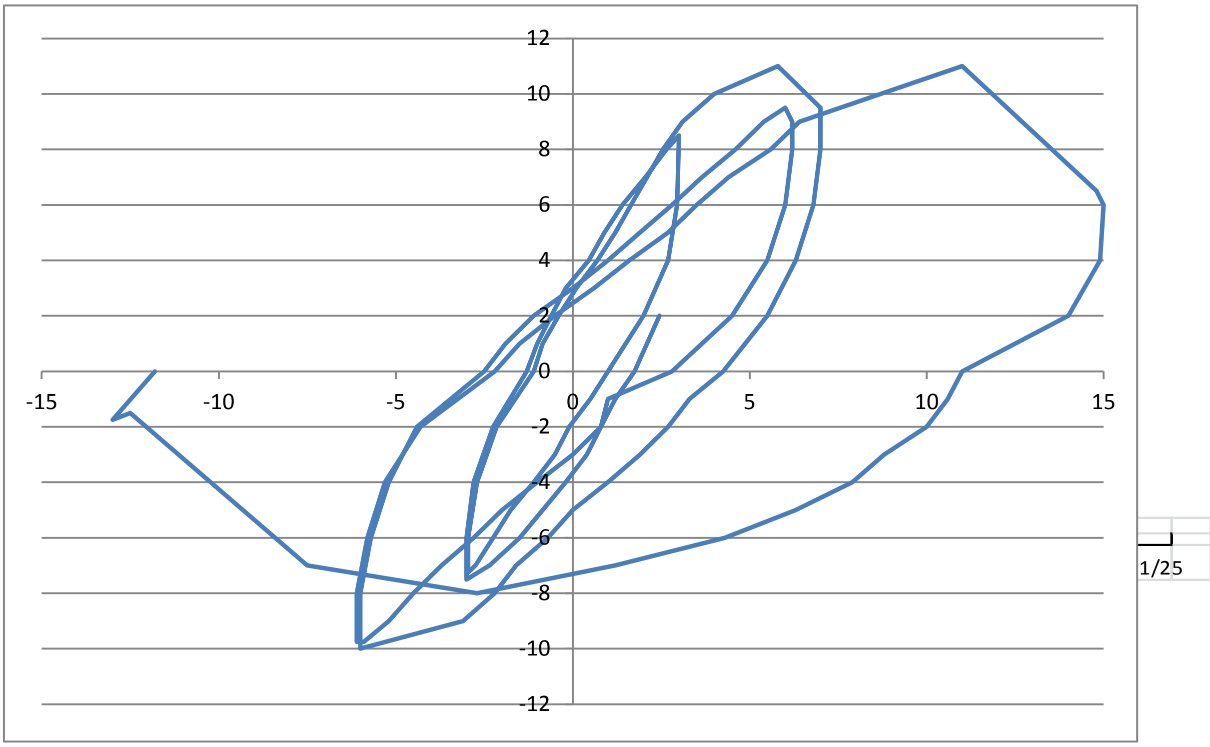
Load-deflection curve, No.4

1. Displacement transducer (average of four DT) -Load cell

Diagonal crack developed



2. Load meter of Jack-Dial Gauge (left upper)



Specimen No.5 2013/11/12 suspended and wall opening on 13

Specimen retrofitted by RC wall.

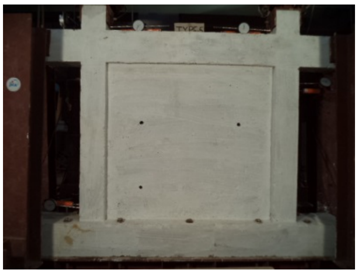
Concrete strength is 1552 psi at 28 days (10.9N/mm2).

Design concrete strength for retrofit wall was 16^18N/mm2.

There is the limitation of capacity 25 ton (practically 23ton) for horizontal hydraulic jack.

Strength of the specimen was higher than the capacity. After the 5th cycle, loading was suspended, and providing small rectangular opening (200mm x 250mm) on the wall to reduce strength approximately 20%, then re-loading was started.

Slippage at the boundary of RC bottom beam and steel foundation beam with approximately 0.5~0.8mm for positive and negative loading, and the result was adjusted by DT located at the bottom of column.

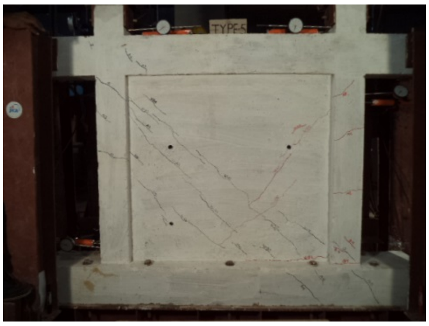


Behavior

R=0 (story deflection angle = story deflection/ story height), 0th cycle, vertical loading 16 ton, vertical deflection was 1.10mm, which is 0.0936% of storey height 1,175mm.

Out of plain movement (torsion) occurred, more than +10mm at right side and -8mm for left side.

R = δ /h **< 1/400**, 1st and 2nd cycle, δ <2.94mm



Initial stiffness ; 2.0ton/0.08mm=25.0ton/mm, 4ton/0.2mm=20ton/mm.

Max. load: positive 1st, 18.5ton. 2nd, 20.6ton, negative 1st, 17.5ton, 2nd 17.8ton

Diagonal crack occurred at top of left column, and diagonal crack also occurred at RC wall at positive and negative loading of 1st cycle.

Horizontal crack (tension crack??) observed at middle of left column at positive loading.

Horizontal crack (tension crack??) observed at middle of right column at negative loading.

Horizontal crack occurred at bottom of right column and right side wall.

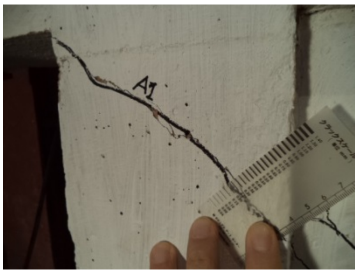
No cracks were observed at the boundary between bottom of upper beam and top of wall.

R = δ /h **< 1/200**, 3rd and 4th cycle, δ <5.88mm

Max. load: positive 3rd, 23.3ton(limit of jack, at 4.3mm). 2nd, 23.3ton (limit of jack at 4.5mm),

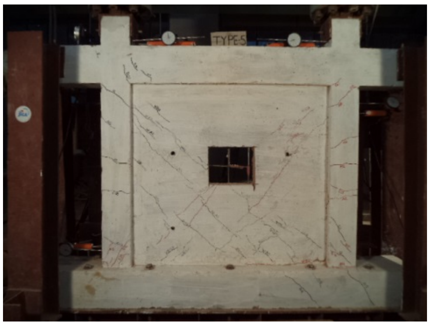
negative 1st, 21.2ton, 2nd 19.5ton
Horizontal crack (tension crack??) observed at left column, diagonal crack developed at wall.
No cracks were observed at the boundary between bottom of upper beam and top of wall.

R = δ /h **< 1/100**, 5rd and 6th cycle, δ <11.75mm
5th cycle; positive 23.3ton (jack limitation) at 5.0mm, negative 23.0ton (jack limitation) at 8.5mm. 12 November 2013.

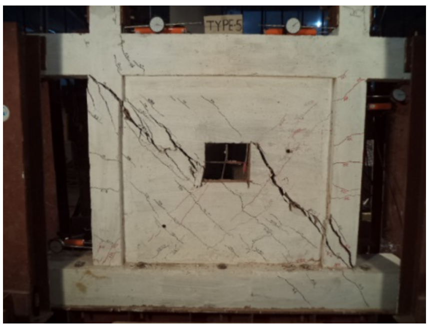


Diagonal **c**rack width of left column is 0.3mm, right column is 0.1mm shear crack of column

Wall opening (200mm x 250mm) was provided on 13 November 2013,



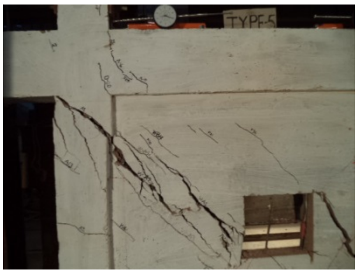
DG for checking of slide at base of specimen



6th cycle, positive loading, shear failure occurred 19.6 ton at 5.0mm, horizontal load reduced from 19.6 ton to 4.5ton at 22.5mm. Axial load dropped from 16ton to 8.5 ton for both columns. Tried to increase axial load to 12 ton, but reduced to 7ton (left column) and

11 ton (right column). Horizontal load reduced to 0.5 ton at 38.5mm.
Decline of vertical strength occurred from 16ton at 7.75mm to 13.8 ton (left column), and 14.3ton (right column) at 10.9mm

Shear failure at deflection 22.5mm

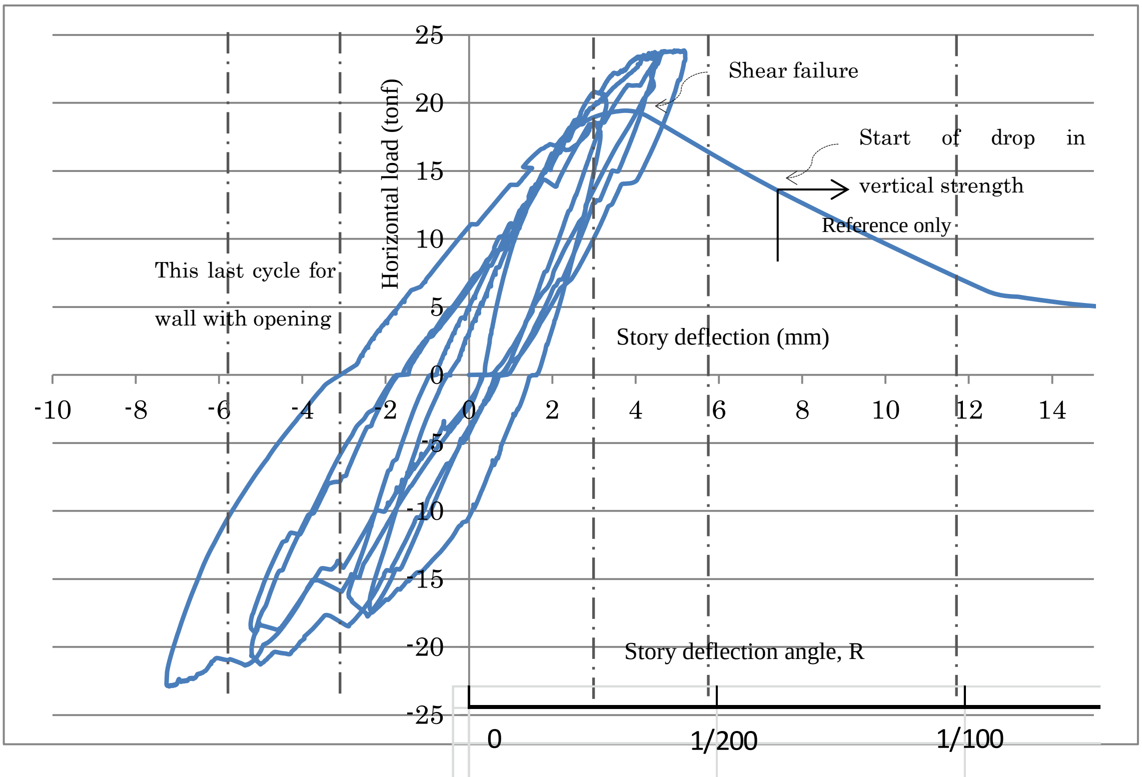


Failure n at deflectio 38.5mm

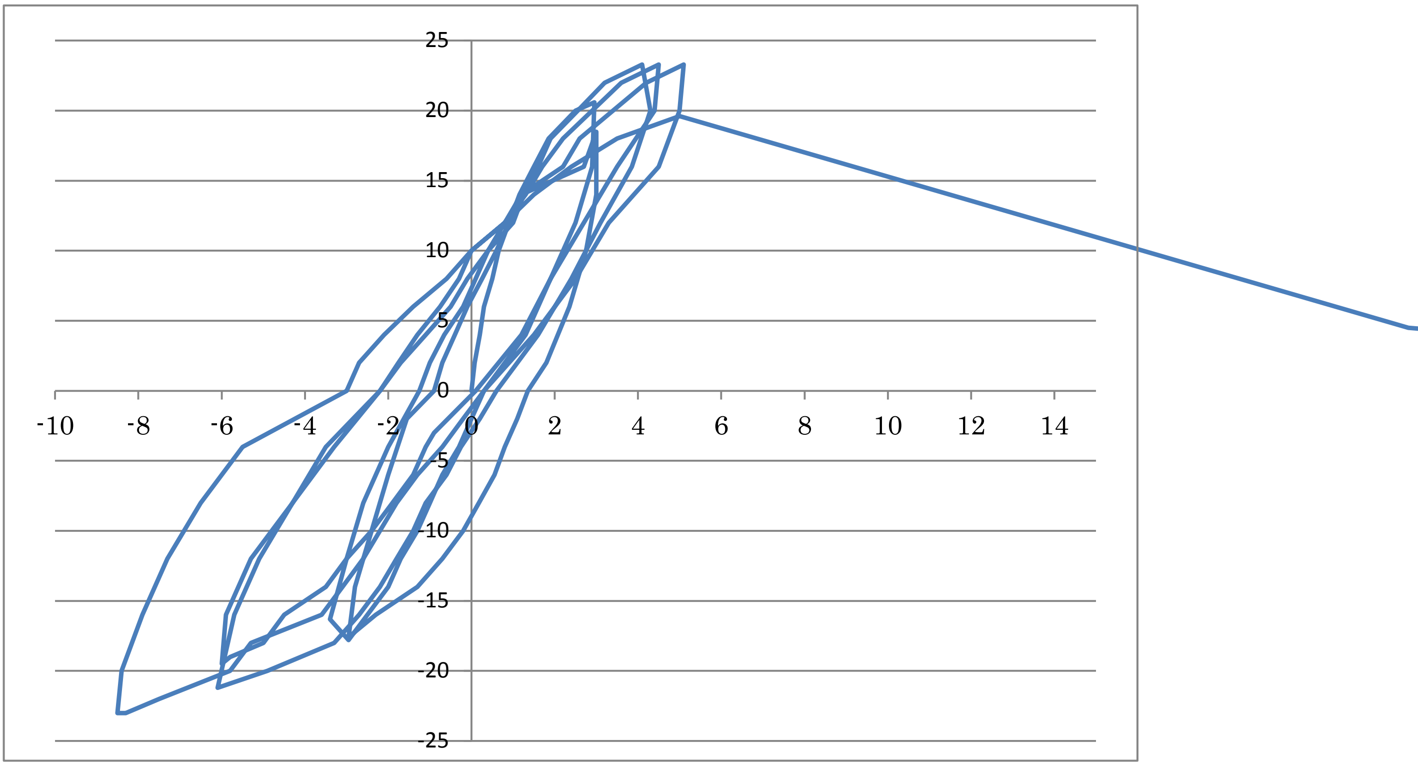
Rear side

No.5Load- deflection,

1. Average DT and load cell, Jack capacity+/-23ton. After the providing wall opening, loading started and deflection of DG was adjusted.



2. Upper DG and Load meter



Specimen No.6 (Retrofitting by Steel Braced Frame)

Behavior

R=0 (story deflection angle = story deflection/ story height), 0th cycle, vertical loading 16 ton, vertical deflection was 1.31mm.

Out of plain movement (torsion) occurred, more than +2.3mm (rear side) at right side and +2mm (rear side) at left side.

Note: According to the tensile test of re-bar 10mm, yield strain is 0.161% (=yield stress/young's modulus=350N/mm2/2.17x10^5N/mm2).

R = δ /h **< 1/400**, 1st and 2nd cycle, δ <2.94mm

Initial stiffness ; 2.0ton/0.1mm=20.0ton/mm, 4ton/0.25mm=16ton/mm.

Max. load: positive 1st, 15.7ton at 2.95mm. 2nd, 18.0ton at 3.0mm, negative 1st, 17.ton at 2.9mm, 2nd 16.6ton at 3.1mm.

During the 1st positive loading from 14.0 ton to 15.7ton, diagonal crack occurred at top and middle of left column. Diagonal crack occurred at beam.

Diagonal crack occurred at the top of right column during 1st negative loading.

Cracks occurred at grout mortar of vertical portion.

R (story deflection angle = story deflection/ story height)= δ /h **< 1/200**, δ <=5.88mm ,3rd and 4th cycle,

Max. load: positive 3rd, 22.0ton at 5.2mm reduced to 20.8ton at 7.3mm. 2^{nd}, 20.0ton at 5.1mm and increased to 6.1mm.3.0mm, negative 3rd, 22.0ton at 6.2mm, 4th 20.5mmton at 6.0mm.

New diagonal crack occurred at middle of left column at 3^{rd} positive cycle.

After the 3^{rd} cycle, left lower DT/DT has some error due to a needle on a crack.

Slight Buckling of out of plain direction of left bracing was observed at 4^{th} cycle of negative loading.

R < 1/100 (δ < 11.75mm), 5^{th} cycle, positive 20 ton at 9.0mm reduced to 14 ton at 20.9mm.

Shear failure occurred at left column that developed diagonal crack observed at 3^{rd} cycle, and penetrated grout mortar portion.

Failure with diagonal and vertical crack occurred at left column.

Axial load of 16 ton was maintained, and reduced to 14 ton for left column and right column maintained 16ton. Buckling of left frame observed, which acted as a column.

Horizontal strength of 12ton was observed at 26mm, and vertical load dropped to 10to for left column.

Out of plain direction buckling was observed at right steel bracing.

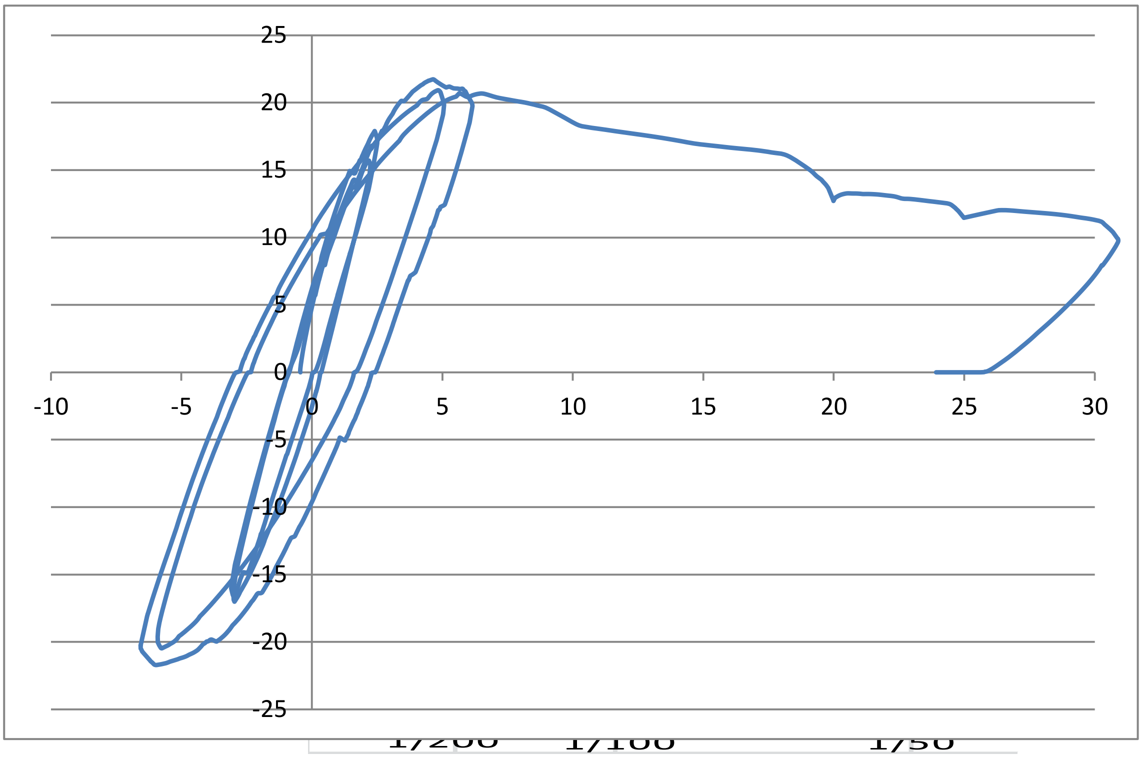
Observed slippage at the base was 0.15mm after the 5^{th} cycle, which will be negligible.

Failure at deflection 20.9mm

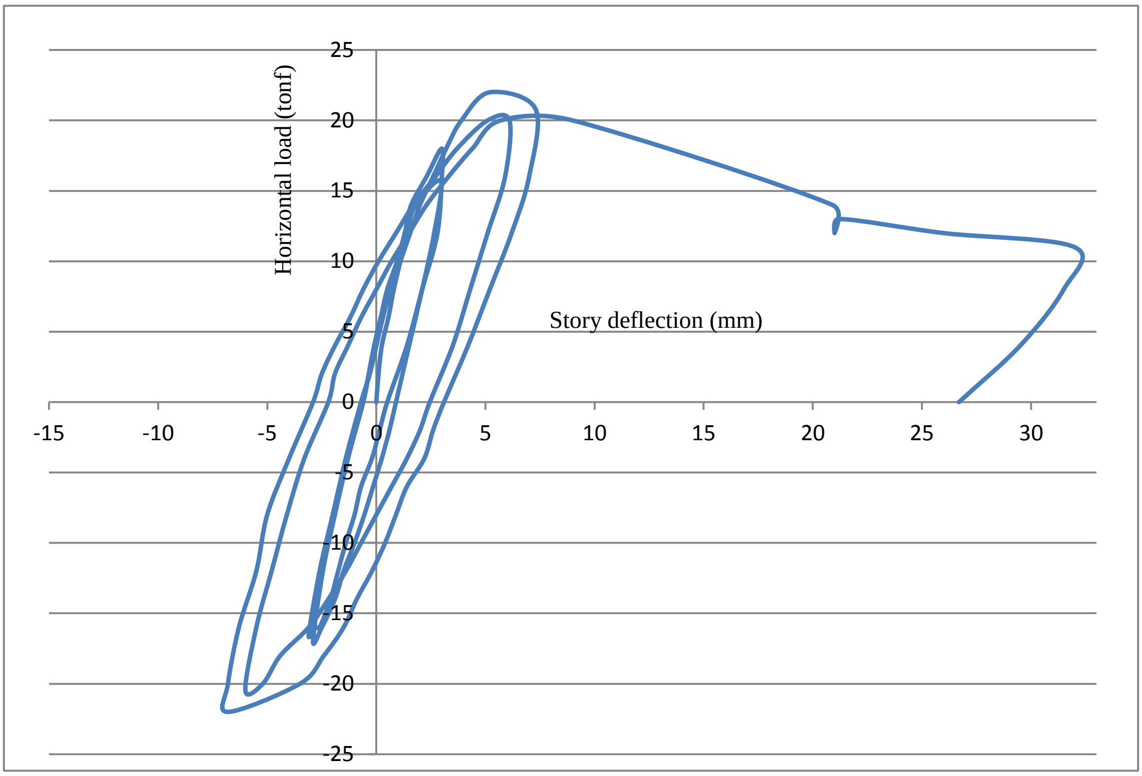
After the loading, at 26mm

Load- deflection, No.6

Load cell and DT



2. Upper DG and Load meter



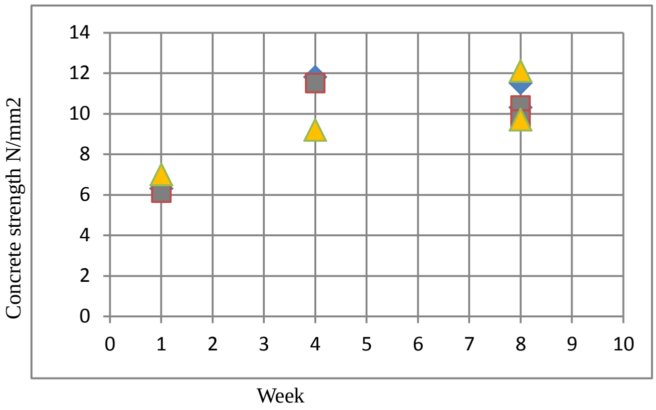
2.4. Material test

1) Concrete Strength

Result of concrete strength for the specimen (UAP). Concrete of 6 specimens was casted on 6 September 2013. Concreting of 3 cylinders for 6 weeks was casted on 30 October.

Table 1.1 (Unit: N/mm2)

	1 week (13/Sep)	4 weeks (4/Oct)	8 weeks (30/Oct)	8 weeks (1/Nov)
No.1	6.3	11.8	10.3	11.5
No.2	6.1	11.5	10.4	9.7
No.3	7	9.2	12.1	9.7
Average	6.5	10.8	10.6	



2) Trial Mix

Trial mix was done for 3 different type of mix using brick chips on 10 July 2013, and mix no. 8 was adopted for the low strength concrete (not more than 13.5N/mm2).

Table-2 Design Mix (by Prof. Tarek, UAP)

Mix No.	Maximum Aggregate Size (mm)	W/C	Sand to aggregate absolute volume ratio	Cement Content (kg/m3)	Water Content (kg/m3)	Fine Aggregate Content (kg/m3)	Coarse Aggregate Content (kg/m3)	Volumetric Ratio*
3	10	0.65	0.44	230	149.5	865	898	1:3.5:4.2
7	10	0.80	0.44	230	184.0	826	857	1:3.4:4.0
8	10	0.90	0.44	230	207.0	800	830	1:3.3:3.9

Table-3 Strength result of trial mix

Mix. no	W/C ratio (%)	Slump (cm)	8 days, on 18 July	Ave. N/mm2 (Ave. psi)	29days, on 8 Aug.	Ave. N/mm2 (Ave. psi)
3	65	0	6.3	6.5 (941) a lot of voids on the surface of concrete were observed caused by poor compaction	8.1	9.2 (1,339)
			6.9		9.6	
			6.3		10.0	
7	80	7	7.1	7.2 (1,051)	8.4	9.1 (1,326)
			7.3		9.8	
			7.4		9.3	
8	90	15	5.8	6.4 (926)	8.9	8.7 (1,268)
			7.0		9.8	
			6.3		7.6	

Note: Sand and brick chips with wet condition at surface were used for the trial mix.

Mix No.3 Mix No.7 Mix No.8

Photo-1 Measurement of Slump value

Strength of non-shrink grout mortar

Mortar was grouted for frame specimen No.5 and No.6 on 8 October and tested on 14 November 2013.

Table

	Height (mm)	Diameter (mm)	Crushed load (kN)	Crushed strength (kN/mm2)	Average (kN/mm2)
1	200	103.7	344.	40.7	39.6
2	200	102.3	316	38.4	
3	--	--	--	--	

Note: Stone chip was used.

Concrete strength for shear wall

Concrete wall was casted for frame specimen No.5 on September 7 and tested on 7 October 2013.

Table

	Height (mm)	Diameter (mm)	Crushed load (kN)	Crushed strength (kN/mm2)	Average (kN/mm2)
1	200	103.5	101.	12.0	10.7
2	200	99.1	82.	10.6	
3	200	104.2	82.	9.6	

Note: Stone chip was used. 31 days.

Mortar strength test for brick wall

Brick wall work was done on 6 October for frame specimen No.3 and No.4, and strength test of mortar was done on 4 November 2013

Table

	Cube size (mm)	Crushing Load(kN)	Strength(N/mm2)	Average (N/mm2)
1	52.5	12.7	4.6	Ave. 4.5
2	51.8	11.5	4.3	
3	52.4	12.7	4.6	

Note: brick chip was used.

Photo Fabrication of Specimen No.5 and No.6

3) Reinforcing bar 2013/August

(1) Summary of re-bar and steel plate material test

Re-bar tests of Bangladesh made used for the structural test are summarized as follows.

Re-bars(Unit: N/mm2)、Specified yield stress of re-bar: 275Mpa (275N/mm2),

Specified yield stress of steel plate: 275Mpa (275N/mm2),

Case 1(BUET), yield stress (N/mm2) only shown, there are 5 universal machines at the lab of BUET.

Bar	No.	Section area (mm2)(diameter)	Yield stress (N/mm2)	Tensile stress (N/mm2)	Elongation %	Yong's modulus X 10^5N/mm2
Plain bar 10mm	1	76.97 (9.9)	325	455	28.	2.04 x10^5
	2	76.97 (9.9)	325	460	26.	2.00 x10^5
	3	74.97 (9.9)	310	450	29.	2.02x10^5
	Ave.	76.97.	**320**	455	28.	2.02 x10^5
Plain bar 6mm	1	42.99 (7.4)	314	418	27.	1.96 x10^5
	2	41.85 (7.3)	334	430	27.	1.97 x10^5
	3	42.99 (7.4)	314	418	25.	1.99x10^5
	Ave.	42.60.	**353**	422	26	1.97 x10^5
Deformed bar 10mm	1	79.0	270	420	24	1.82 x10^5
	2	79.0	260	420	28	1.82x10^5
	3	79.0	245	420	28	1.82x10^5
	Ave.	79.0 (nominal)	**258**	420	26	1.82x10^5
Steel plate	1	88=4.12x21.4	330	510	19	1.85 x10^5
	2	94=4.30x21.9	400	510	18	1.85 x10^5
	3	90=4.12x21.8	330	510	18	1.91x10^5
	Ave.	90.7	**353**	510	18	1.87 x10^5

Case 2 (Building Material Testing Center, Urawa Japan), 31 July 2013 浦和建材センター

Bar	No.	Section area (mm2)(diameter)	Yield stress (N/mm2)	Tensile stress (N/mm2)	Elongation %	Yong's modulus X 10^5N/mm2
Plain bar 10mm	1	76.77 ( )	346	471	32.	--
	2	76.41 ( )	345	477	34.	--
	3	74.72 ( )	358	493	34.	2.17x10^5
	Ave.	75.97.	**350**	456	33	--
Plain bar 6mm	1	39.97 ( )	387	473	N.A.	--
	2	44.73 ( )	332	428	33	--
	3	46.20 ( )	340	437	N.A.	2.15x10^5
	Ave.	43.63.	**353**	456	33	--
Deformed	1	79.0	276	425	38	--

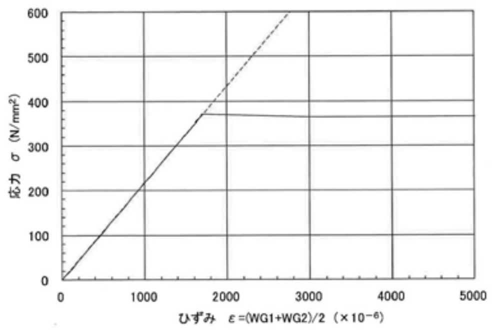
bar 10mm	2	79.0	277	425	35	--
	3	79.0	269	419	35	$1.99x10^5$
	Ave.	79.0 (nominal)	**274**	423	36	--
Steel plate	1	105.3	346	537	30	
	2	108.2	375	542	30	
	3	102.3	368	549	29	$2.09x10^5$
	Ave.	315.8	**363**	443	30	

Note

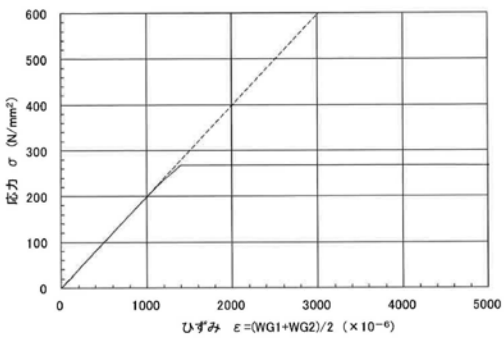
1) Steel plate is fabricated from angle member as type 5 of JIS, which is 25mm width.

Stress-strain curve, Urawa building material lab. in Japan

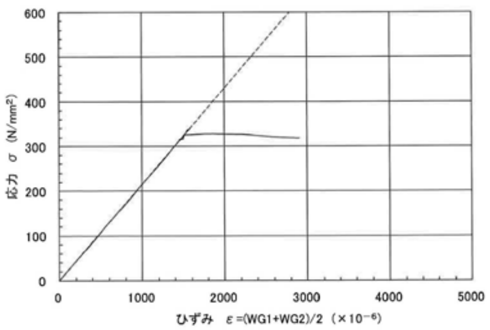
φ10mm　　　　　　　　　　　　　　D10mm



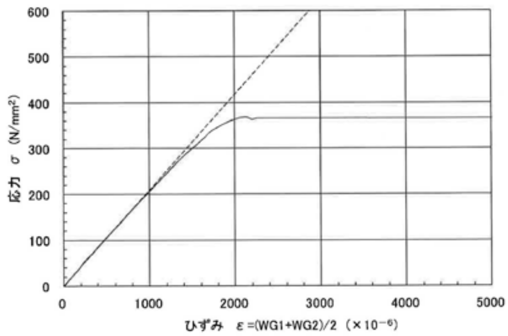
図−1　応力−ひずみ曲線　（丸鋼φ10㎜）



図−3　応力−ひずみ曲線　（異形棒鋼D10）



図−2　応力−ひずみ曲線　（丸鋼φ6㎜）



図−4　応力−ひずみ曲線　（鋼板t=4㎜）

4) Comparison of strength between cylinder test and concrete core sampling test (reference only)

Diameter; 50mm

	Height (mm)	Diameter (mm)	Crushed load (kN)	Crushed strength (kN/mm2)	L/D	Correction factor	Corrected strength (kN/mm2)	Average (kN/mm2)
1	96.8	49.5	18.1	9.4	2.0	1.0	9.4	9.0
2	101.2	49.4	17.1	8.9	2.0	1.0	8.9	
3	101.0	49.6	16.8	8.7	2.0	1.0	8.7	

Diameter; 100mm

	Height (mm)	Diameter (mm)	Crushed load (kN)	Crushed strength (kN/mm2)	L/D	Correction factor	Corrected strength (kN/mm2)	Average (kN/mm2)
1	150.4	99.3	63.7	8.2	1.5	0.96	7.9	9.0
2	151.8	99.3	88.0	11.3	1.5	0.96	10.9	
3	150.0	99.2	66.7	8.6	1.5	0.96	8.3	

Note: Result of concrete cylinder test was 10.6N/mm2 at 4 weeks. Strength of core was 15% lower than cylinder strength. (9.0/10.6 = 0.849).

2.5. Consideration

1) Evaluation of horizontal strength of frame

Comparison of experimental result and analysis (unit; ton)

Observed maximum load for positive and negative loading are compared with the calculated strength as shown below (value of load meter is shown).

	Experimental load, Qe (ton)			Analytical strength at collapse mechanism, Qa (ton)			
Specimen no. (date)	Positive loading	Negative loading	Average	Calculated strength, Qa	Qe(posi.) /Qa	Qe(nega.) /Qa	Note
1 (Nov/5,6)	4.5	4.0	4.25	4.4	1.02	0.91	Typical frame
2 (Nov/9)	4.0	5.0	4.50	4.4	0.91	1.14	End frame
3 (Oct/28)	7.7	6.0	6.85	3.1+ 2.2=5.6 Shear + flex.	1.38	1.07	Frame with brick standing wall
4 (Nov/3)	11.0	10.0	10.5	Shear of brick wall, 10.5-3.1x2 = 4.3 Shear stress, 4300/6x105=6.8kg/cm2			Frame with full brick wall
5 (Nov/12,16)	23.0 Limit of jack	23.0 Limit of jack	--	3.1(shear)x2+12.0(RC panel)=18.2, Qe/Qa=23/18.2=1.26 (Punching shear of column, 4.9).			Retrofitted by RC shear wall
5 (Nov/16)	19.6	--		Opening 20cmx25cm, reduction 0.19, Shear strength,18.2x0.81=14.7 Qe/Qa=19.6/14.7= 1.33			Retrofitted by RC shear wall with opening
6 (Nov/18)	22.0	22.0	22.0	3.1(shear)x2+12.5 (steel brace)=18.7 Qe/Qa=22/18.7=1.18 (punching shear of column, 4.9)			Retrofitted by steel braced frame

Concrete, supposed Fc= 12N/mm2 ~ 10N/mm2 (average concrete strength at 8 week is 10.6N/mm2)

Shear force by flexural strength of a column (Eq. A1,1-1)

Q= 11.0~10.5*10^3 kN.mm /h (975mm) = 22.6~21.6kN

Shear strength of a column (Eq. A1-1.2)

Qu1=32.1~30.8kN

In case coefficient 0.068 (mean value) is applied instead of 0.053,

Qu2=34.5~33.0kN

In case reduction factor for low strength concrete (σb <13.5), Yamamoto's equation, is applied.

kr=0.056*σb+0.244=0.056*10.4+0.244=0.826

Qu3=26.5~25.5kN

Punching shear, Qp=48.9kN

Shear strength of RC wall panel, wQsu=120kN

Shear of steel brace, Q= (123.3(C)+140(T))cos 61.7°=124.8kN

Mortar strength of brick wall, fc=4.5N/mm2

Basic Information

Axial strength of column

Re-bar: 6-10mm diameter, A=6x 76.9mm2=462mm2, σy=320N/mm2

A*σy=147.8kN

Concrete: Fc 10.6N/mm2 (low strength concrete, average of 8 weeks)

b*D*Fc=150mm*150mm*10.6N/mm2= 238.5kN

Total A*σy + b*D*Fc =147.8kN + 238.5kN =386.3KkN

Axial force: N= 1600kg (163.3kN)

Axial force ratio: N/ (b*D*Fc) = 163.3/238.5= **0.68**

In case design concrete strength: N/(b*D*Fc) = 163.3*10^3/(150*150*14.0)= 0.52

Axial force ratio against strength:

N/ (A*σy+ b*D*Fc) = 163.3/(147.8+238.5)= **0.42**

Axial force ratio against strength (using design concrete strength):

N/(A*σy+ b*D*Fc) = 163.3/(147.8+315.0)= 0.35

Specimen 2012-No.5: Concrete strength, 16.5N.mm2

Axial force ratio; **N/ (b*D*Fc)** = 163.3/371.3= **0.44**

Axial force and Flexural moment Relation (N- M Interaction Curve)

Stress (Strain) of Re-bar

Plain bar 10mm, E = 2.17x 10^5N/mm2, σ y = 350N/mm2, ε y = 0.00161 (0.161%)

By URAWA building material testing center, Japan

Material (Urawa building material center)

Plain bar ϕ 10, σ y = 350N/mm2

ϕ 6, σ y = 353N/mm2

Deformed bar D10, σ y = 274N/mm2

Steel plate, t=4mm, σ y = 363N/mm2

Concrete, supposed Fc= 12N/mm2 ~ 10N/mm2 (8 week concrete strength is 10.6N/mm2)

Cement mortar of brick wall, fc =

Column

Main bar 6- ϕ 10 Pt= 76.0x3/ 150*123=0.0122

Hoop 6 @150 Pw= 43.6*2/150*150 =0.00388 (Actual size is ϕ 7.45 @195, Pw=0.00298)

Flexural strength of column

N > 0.4bDFc (Eq. A1,1-1, and coefficient 0.7 is used instead of 0.8, because of small dimension)

Mu = {0.7*At* σ y*D + 0.12*b*D^2*Fc}(Nmax- N)/ (Nmax- 0.4*b*D*Fc)

= 11.0~10.5*10^3kN.mm

Flexural strength of beam

(Upper tension) Mu = 18.6*10^3kNmm

(Lower tension) Mu = 11.2*10^3kNmm

Shear force by flexural strength of a column (Eq. A1,1-1)

Q= 11.0~10.5*10^3 kN.mm /h (975mm) = **22.6~21.6kN**

Shear strength of column (Eq. A1-1.2)

Qu1=32.1~30.8kN

In case coefficient 0.068 (mean value) is applied instead of 0.053,

Qu2=34.5~33.0kN

In case reduction factor for low strength concrete (σ b <13.5), Yamamoto's equation, is applied.

kr=0.056* σ b+0.244=0.056*10.4+0.244=0.826

Qu3=26.5~25.5kN

Shear wall

Shear strength of infilled RC panel plus shear strength of column was evaluated.

Steel braced frame

Steel brace

2L-30*30*4.2 (A=386mm2, σ y=363N/mm2), since designed 2L-38:38*3.0 (603.2mm2, σ y=250N/mm2) was not available.

iy=0.908cm2(iy of L-30*30*3 is used)

λ (slenderness ratio)=1100/2*9.08=60.6 >60, effective λ = 700/2*9.08=38.5

fc=191*1.5/363/325= 320kg/mm2

Com. C=320*386mm2=123.2kN

Ten.T=363(σ y) *386 mm2=140.1kN

Brace Q= (C+T)cos 61.7° =124.8kN

Punching shear of a column Qp=48.9kN (Fc= 10N/mm2)

Shear strength of a column Qs=33.0kN (Hoop @195, Pw=0.00298)

Total Q1= 48.9+33.0+124.8 = 206.7kN

Q2= 33.0*2 + 124.8 = 190.8kN

Post installed anchor, embed length 8*da, D10*8=80+10=90mm (length of hole)

Shear strength

Qa1(steel)=0.7* σ y*a = 0.7*235*1.1*78.5 = 14.2kN

Qa2(pressure) = 0.4√(Ec* σ b) *sAe= 0.4*√(1.7*10^4*10) *78.5 =12.9kN < 14.2,

@100 = 129kN

Shear strength of stud (ϕ 8mm headed stud)

Qud=0.64* σ max*As=0.64*400*1.1*50 = 14.1kN, @100 double, 28.2kN > 129kN

Mortar strength of brick mortar

4.5N/mm2

Appendix

In the following formula, 0.7*at* σ *D was used instead of 0.8*at* σ *D, considering the small size of the specimen.

$$\text{For } N_{max} \geq N > 0.4b \cdot D \cdot F_c$$

$$M_u = \left\{0.8a_t \cdot \sigma_y \cdot D + 0.12b \cdot D^2 \cdot F_c\right\} \cdot \left(\frac{N_{max} - N}{N_{max} - 0.4b \cdot D \cdot F_c}\right)$$

$$\text{For } 0.4b \cdot D \cdot F_c \geq N > 0$$

(N・mm)

$$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.5N \cdot D \cdot \left(1 - \frac{N}{b \cdot D \cdot F_c}\right)$$

$$\text{For } 0 > N \geq N_{min}$$

$$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.4N \cdot D$$

(A1.1-1)

where:

N_{max} = Axial compressive strength $= b \cdot D \cdot F_c + a_g \cdot \sigma_y$ (N).

N_{min} = Axial tensile strength $= -a_g \cdot \sigma_y$ (N).

N = Axial force (N).

a_t = Total cross sectional area of tensile reinforcing bars (mm^2).

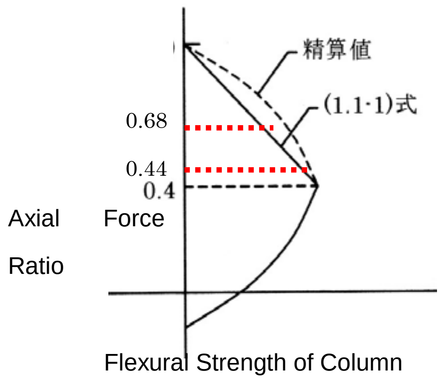
a_g = Total cross sectional area of reinforcing bars (mm^2).

b = Column width (mm).

D = Column depth (mm).

σ_y = Yield strength of reinforcing bars (N/mm^2).

F_c = Compressive strength of concrete (N/mm^2).



Shear strength of column (ref.1)

$$Q_{su} = \left\{ \frac{0.053 p_t^{0.23} (18 + F_c)}{M/(Q \cdot d) + 0.12} + 0.85 \sqrt{p_w \cdot {}_s\sigma_{wy}} + 0.1\sigma_0 \right\} \cdot b \cdot j \qquad \text{(N)} \qquad \text{(A1.1-2)}$$

where:

p_t = Tensile reinforcement ratio (%).

p_w = Shear reinforcement ratio, p_w =0.012 for $p_w \geq 0.012$.

${}_s\sigma_{wy}$ = Yield strength of shear reinforcing bars (N/mm^2).

σ_0 = Axial stress in column (N/mm^2).

d = Effective depth of column. D-50mm may be applied.

$\frac{M}{Q}$ = Shear span length. Default value is $\frac{h_0}{2}$.

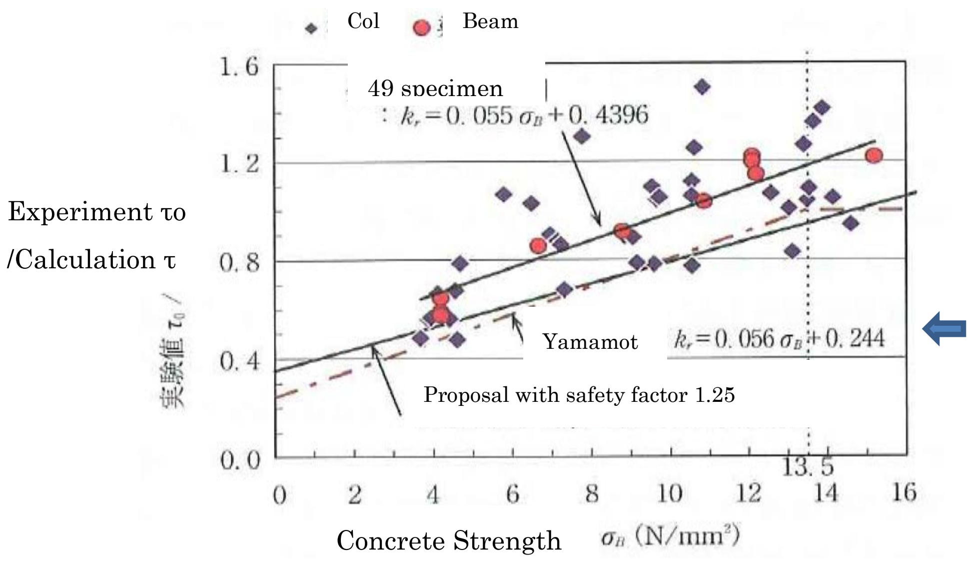
h_0 = Clear height of the column.

j = Distance between centroids of tension and compression forces, default value is 0.8D.

(b) If the value of $M/(Q \cdot d)$ is less than unity or greater than 3, the value of $M/(Q \cdot d)$ shall be unity or 3 respectively in using Eq. (A1.1-2). And if the value of σ_0 is greater than 8N/mm^2, the value of σ_0 shall be 8N/mm^2 in using Eq. (A1.1-2).

Proposed **reduction factor** of shear strength for low strength concrete.

This was not used for the strength evaluation.



Japan Concrete Institute, "Low strength Concrete",

Minami, Concrete Journal, vol. 48, No.7, Jul. 2010

Part 3. Experiment 2012

3.1 General

1) Purpose

Main purposes of the test re shown below.

1. To see the strength and directly the behavior of RC frame till the collapse stage.
2. To disseminate the experiment to other engineers and concerned organization.
3. To get useful data/information related to strength and ductility necessary to evaluate existing RC frame buildings in Bangladesh, and related to issues those may not covered by the Japanese code.

Test results are not necessarily successful, and reasons are shown.

3.2 Testing Plan

Proposed Plan for Structural Experiment is shown below.

1) Outline

1. Reinforced concrete frame with 1 story, 1span will be selected for the experiment.
2. Mid-rise buildings constructed around 30 years ago, and 1/3 scale will be selected.

2) Parameters to be considered

1. Axial force ratio of column (N/BDFc = 0.25, 0.50), to be decoded by actual data
2. Column collapse and beam (or joint) collapse
3. Brick-wall (thickness and height)
4. Lap joint (without hook and no lap joint for main bars)
6. Type of main-bar (plain bar and deformed bar to compare with the bond)

3) Material

Concrete: Fc 14N/mm2 (design mix, and max.) with brick chips, will be decided by the result of trial mix with a few types (strength of 7 days, 28 days, 42 days, 56 days).

Main Re-bar and shear reinforcement: yield stress: 275N/mm2

4) Model (typical)

1. Column, size: 150mmx150mm
   Main bars: 6-φ10mm (round bar)
   Shear reinforcement: φ6mm @150 with 90 degree hook
2. Beam, size: 150mmx 150cm
   Main bars: top 4-φ10mm top and 2-φ10mm bottom
   Shear reinforcement: φ6mm @100 with 90 degree hook
3. Beam column connection; no hoop
4. Brick wall, 250x125x75mm, thickness 125mm with height of 500mm
   250x60x75mm, thickness 60mm with height of 750mm

5) Frame sizes, Height; 1.15m, Span; 1.6m

6) Number of Specimen

Total 7 specimens.

No.	1	2	3	4	5	6	7
Beam	Strong type	Strong type	Strong type	Strong type	Standard type	Standard type,	Standard type,
Main bar	Deformed	Deformed	Deformed	Deformed	Plain	Plain	Deformed

Lap joint	Nill	Nill	Nill	Nill	Lap joint	Nill	Lap joint
Column Main bar Lap joint	Column Plain Lap joint	Column Plain Lap joint	Column Plain Lap joint	Column Plain Lap joint	Column Plain Lap joint	Column Plain Nill	Column Deformed Nill
Brick wall	Nill	Nill	2 layer, 0.5H	1 layer, 0.75H	Nill	Nill	Nill
Axial force ratio	0.25	0.50	0.50	0.50	0.50	0.50	0.50
Note			Ex. wall	Int. wall			
Type of specimen	Type 1	Type 1	Type 1a	Type 1b	Type 2	Type 2a	Type 2b

H: Clear height of column

Axial force ratio (N/BDFc) will be adjusted based on existing data.

7) Plan of loading

Existing reaction frame with hydraulic jack and load cell will be used.

Horizontal load; 250kN capacity, stroke 100mm

Vertical load; 500kN capacity, stroke 100mm

Additional 2 nos. of steel members for horizontal loading will be provided for the reaction frame.

A steel beam will be provided under the test specimen.

8) Loading program (draft)

Repeated static incremental horizontal load is provided.

1/400 of column length 1,000mm, 2.5mm, 2 cycles (step is controlled by load)

1/200 5.0mm, 2 cycles

1/100 10.0mm, 2 cycles

1/50 20.0mm, 2 cycles (step is controlled by displacement)

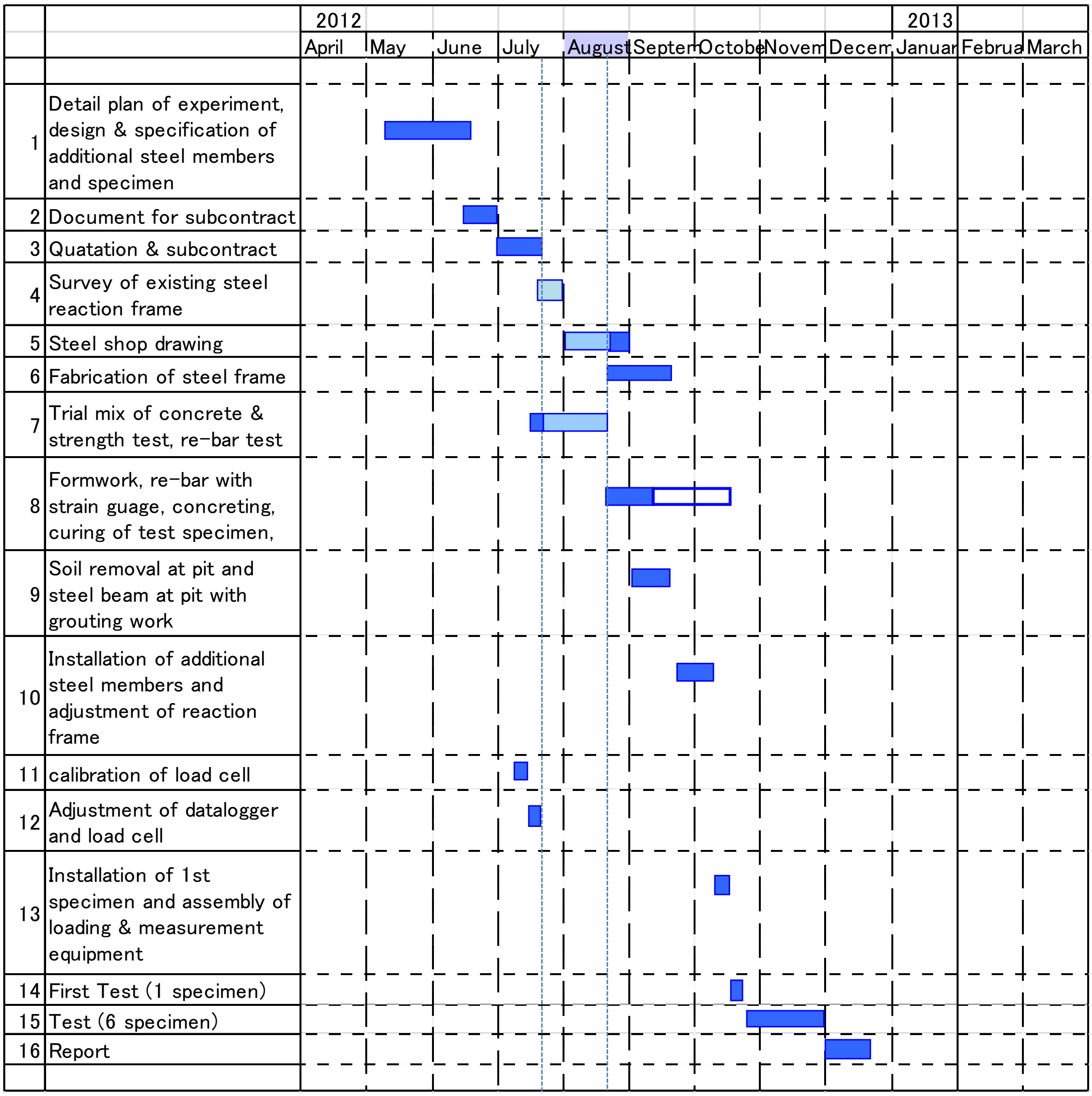
1/25 40.0mm, 2 cycles

Stroke of displacement transducer is supposed to be 100mm (effective stroke is plus and minus 50mm).

9) Place of Experiment

Testing laboratory of Department of Civil Engineering, BUET

10) Schedule



Note:

1) Trial mix of concrete to be done as soon as possible (7 days, 28days, 42days, 56 days).
2) Calibration of load-cell and connection test for data-logger will be done at an early stage.
3) Duration of test is supposed as 2 days for setting and preparation and 2 days for measurement. Total 4 working days for a specimen.
4) Pinned joints (total 4 sets) are requested to fabricate as a part structural steel for loading.
5) Roller for horizontal guide (total 4 sets) will be purchased in Japan.

11) Results

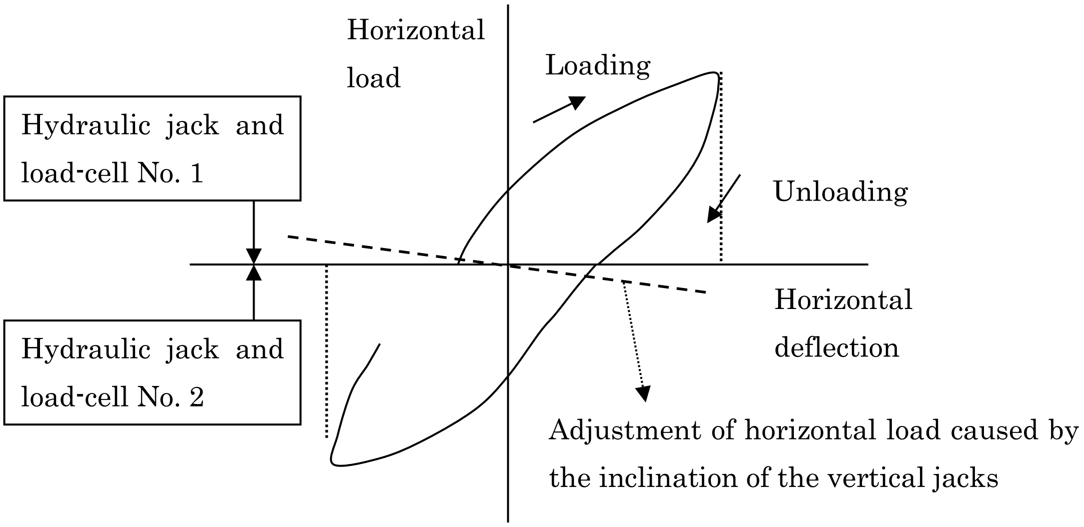
a) Experiment

Load-deflection curve will be provided through the test.

Initial horizontal stiffness, horizontal strength and ductility will be measured.

Failure mode will be observed.

Influence of parameters, such as axial force ratio, beam column joint, brick wall will be reviewed.



Hydraulic jack and load-cell is released when other jack and load-cell is working.

b) Analysis

Analysis for load-deflection will be done by standard method, and will be compared with the experimental results.

Stiffness, crack stress, column flexural strength and shear strength will be estimated.

Beam-column strength will be estimated.

12) Proposed Scope of Work 2012/07/04

		PWD, JET	BUET
1	Detail plan of experiment, design & specification	○	Review and confirmation of detail plan
2	Document for subcontract	○	
3	Subcontract	○	
4	Survey of existing reaction frame	○ (sub contractor)	○(coordination)
5	Steel shop drawing	○ (sub contractor)	
6	Fabrication of steel frame	○ (sub contractor)	
6	Trial mix of concrete & strength test, re-bar test (note 1)	○ (sub contractor), advise on mix design by UAP	
7	Formwork, re-bar, concreting, curing of specimen,	○(sub contractor, supply of strain gauge)	○ (installation of strain gauge)
8	Removal of soil at pit and installation of steel beam	○ (sub contractor)	○(coordination)
9	Installation of additional steel members and adjustment of reaction frame, and new painting	○ (sub contractor)	○(coordination)
10	Calibration of load cell (4 nos.)		○
11	Adjustment of data-logger (20 channels) and load cell		○
12	Laptop computer with software		○
13	Installation of test specimen and removal, and steel frame for guide and measurement	○ (provide labors), Provide 2 nos of roller for guide.	○(advice)
14	Installation of measurement equipment, such as DT, DG	○ (provide 100mm DTx4 with cables, 100mm DGx4, bridgebox x12with cables for strain gauge)	○ (50mm DTx4, 50mm DGx4, 25mmDGx2, magnetx10)
15	Loading and measurement (total 7 specimen)	○ (provide labors)	○ including crack observation and photos, records
16	Report	○(Load-deflection curve by analysis, stiffness and strength by analysis)	○ (Load-deflection curve by test, summary, failure mode and influence of axial force, brick wall, lap joint, plain bar)

Note: 1) DT: Displacement transducer, DG: Dial gauge.

Laboratory of Civil Engineering Department, BUET

Reaction frame

Hydraulic jack and load cell (1)

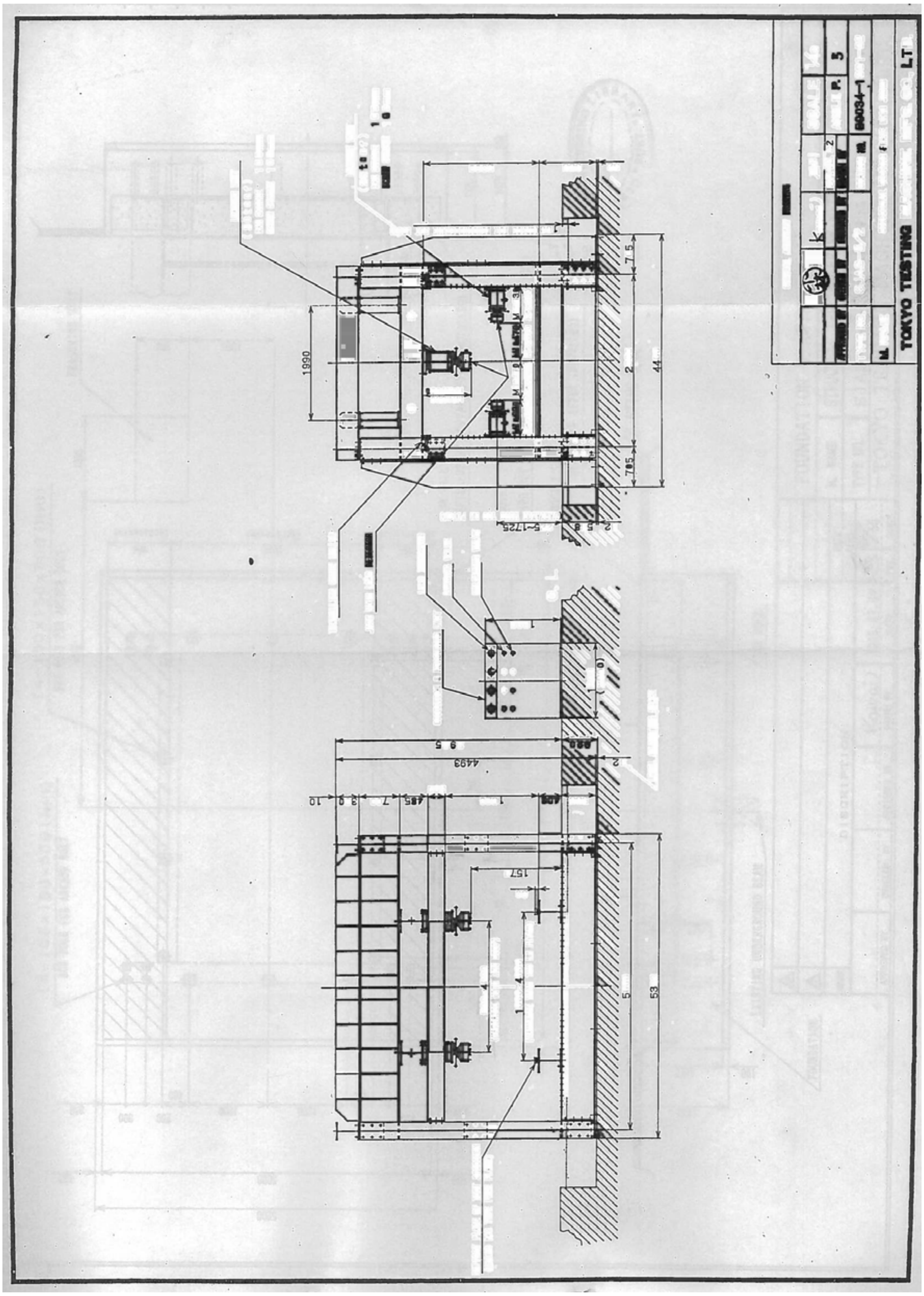
Hydraulic jack and load cell (2)

Control panel

Lift (2ton capacity)

Space for fabrication of specimen

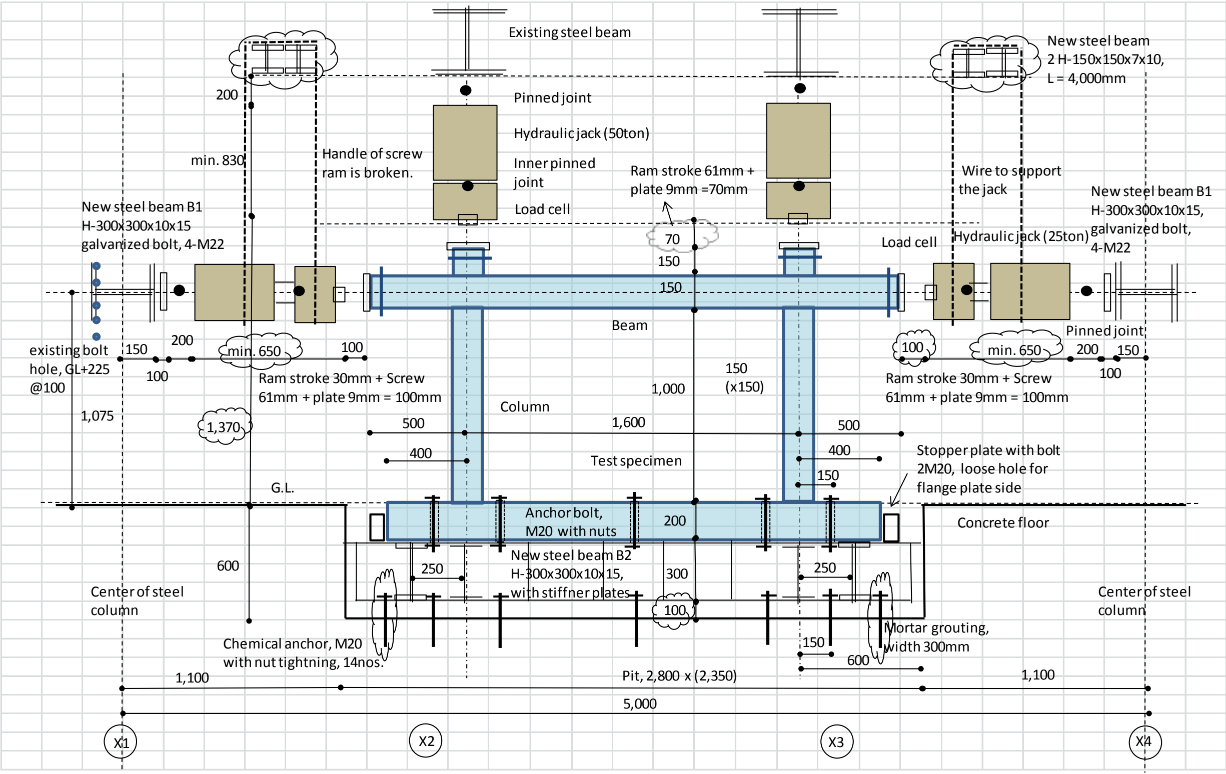
xisting Reaction Frame with Hydraulic Jacks and Load Cell, BUET



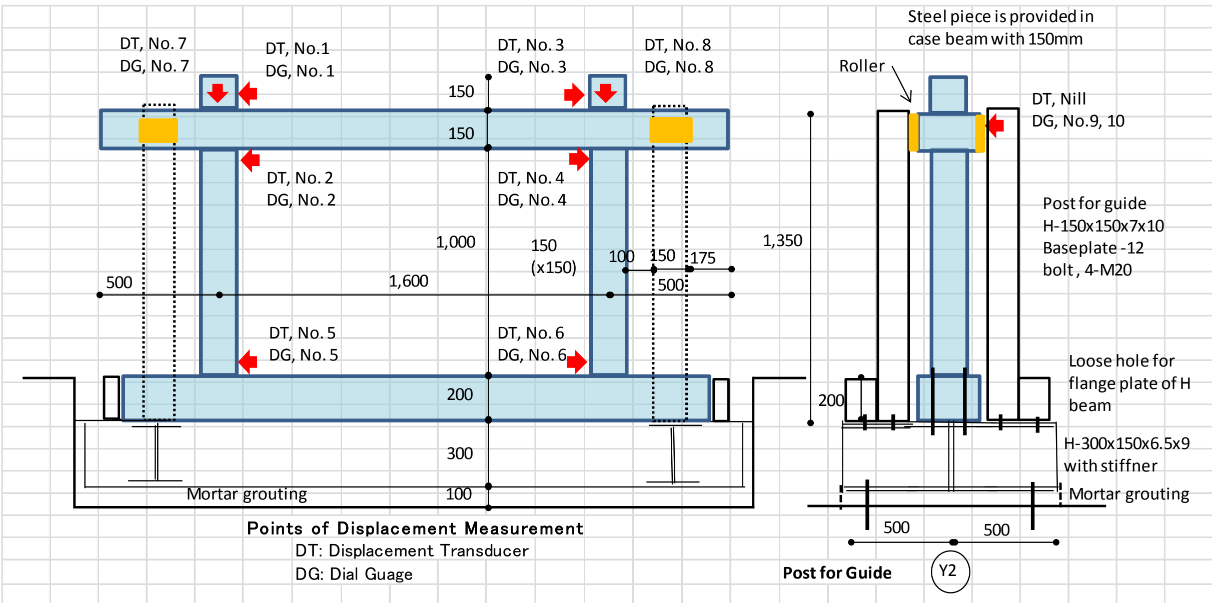
Structural Test by CNCRP

13) Structural Experiment

Plan of Testing Apparatus (unit: mm)

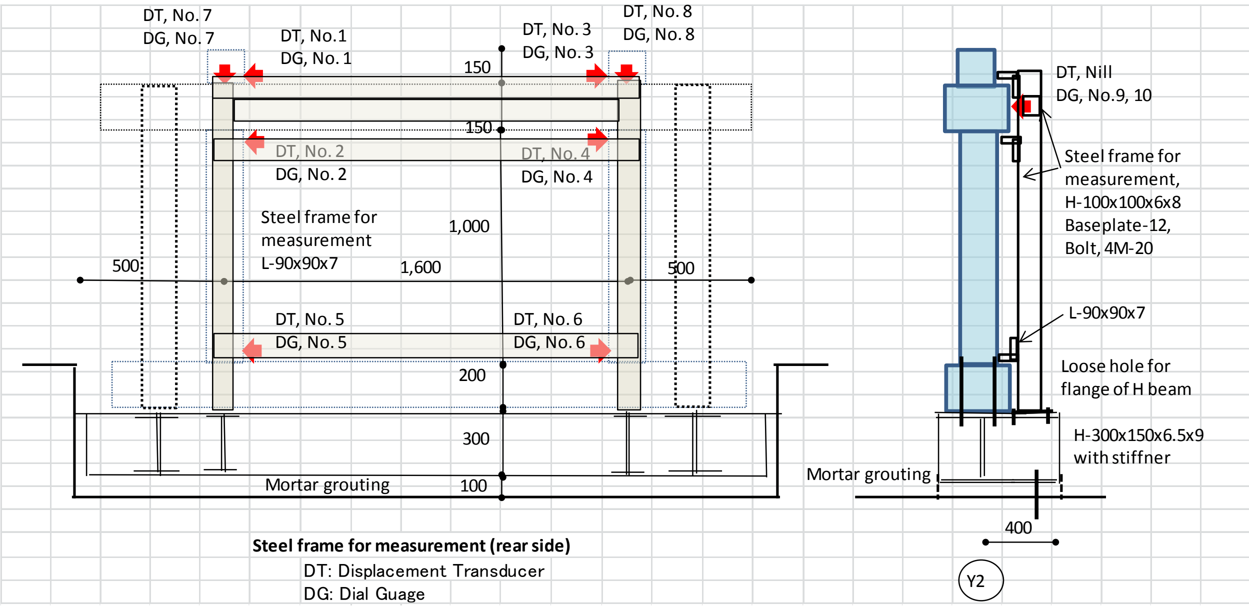


Posts for guide



Note: Roller was not used because of the material availability.

Measurement



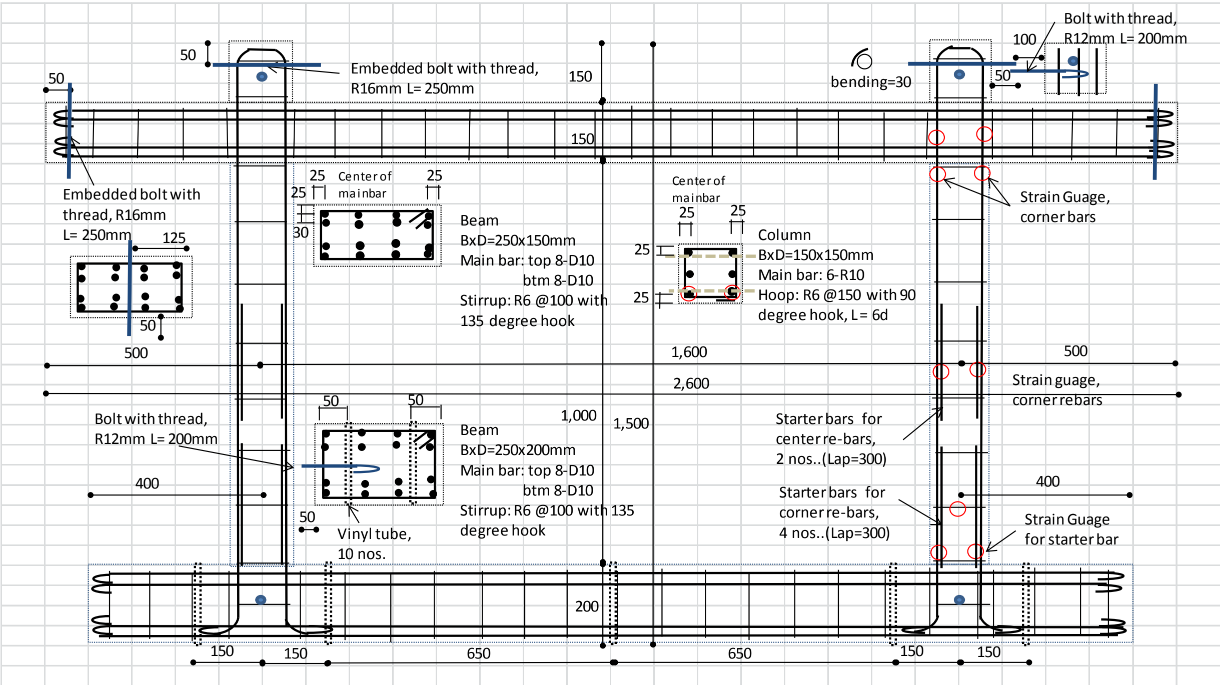
Steel frame for measurement is provided.

Displacement transducer; stroke of 100mm will be used for No.1 through no.4

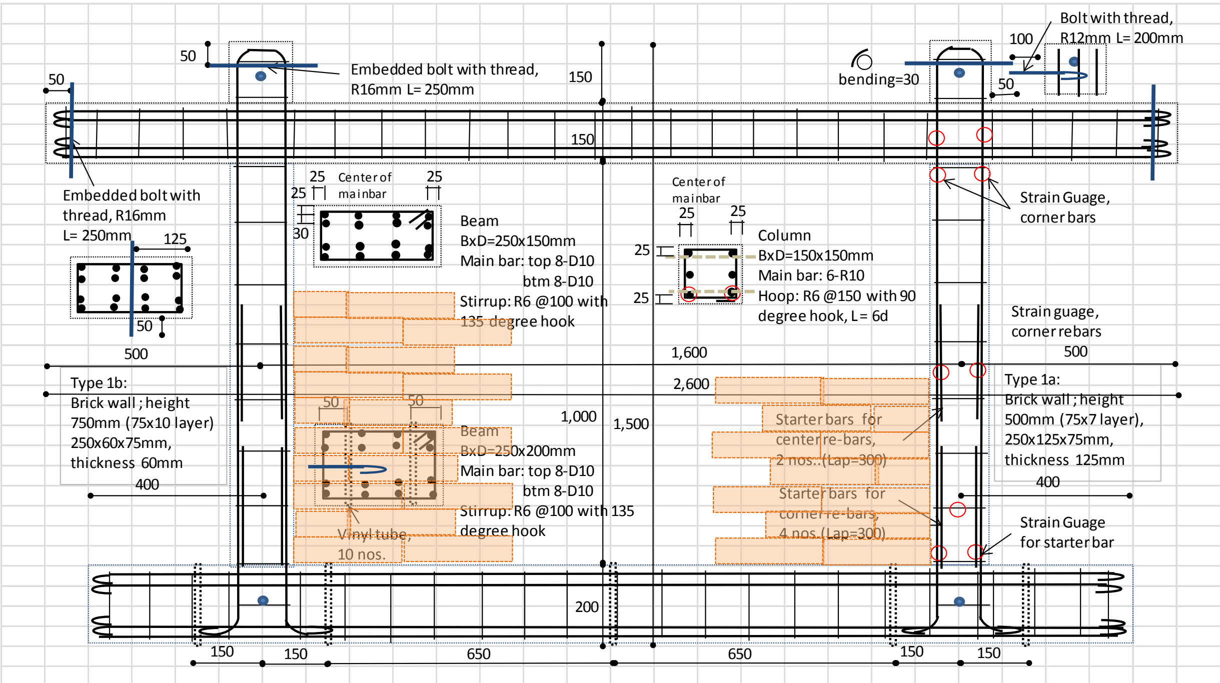
Dial gauge; stroke of 100mm will be used for No.1 through no.4

14) Plan of Specimen

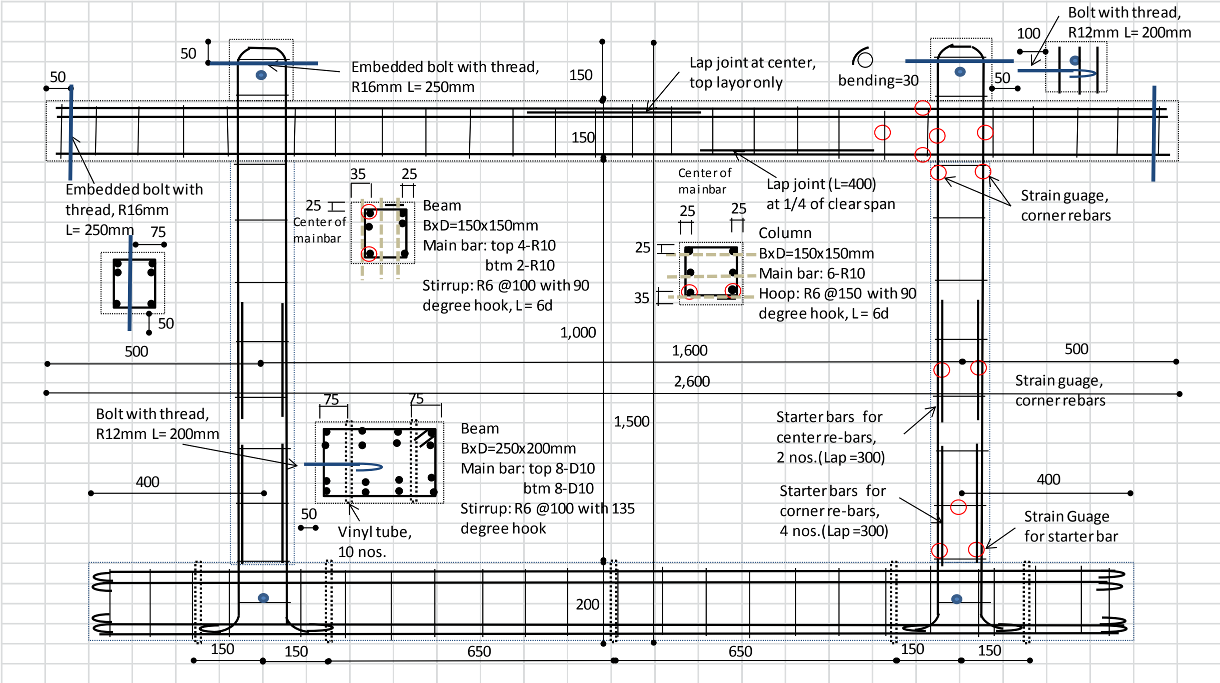
Type 1 (Strong beam and plain bar with lap joint without hook) x 2



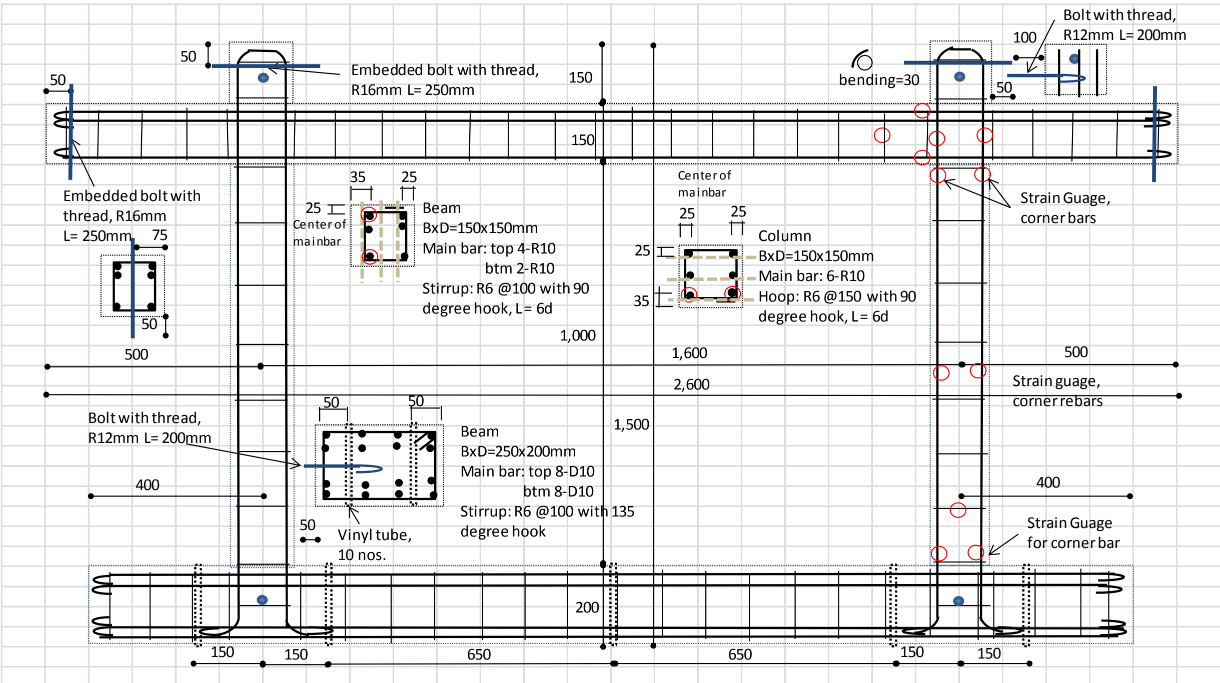
Type 1a & 1b (Strong beam, plain bar and brick wall) x 1 each (total 2)



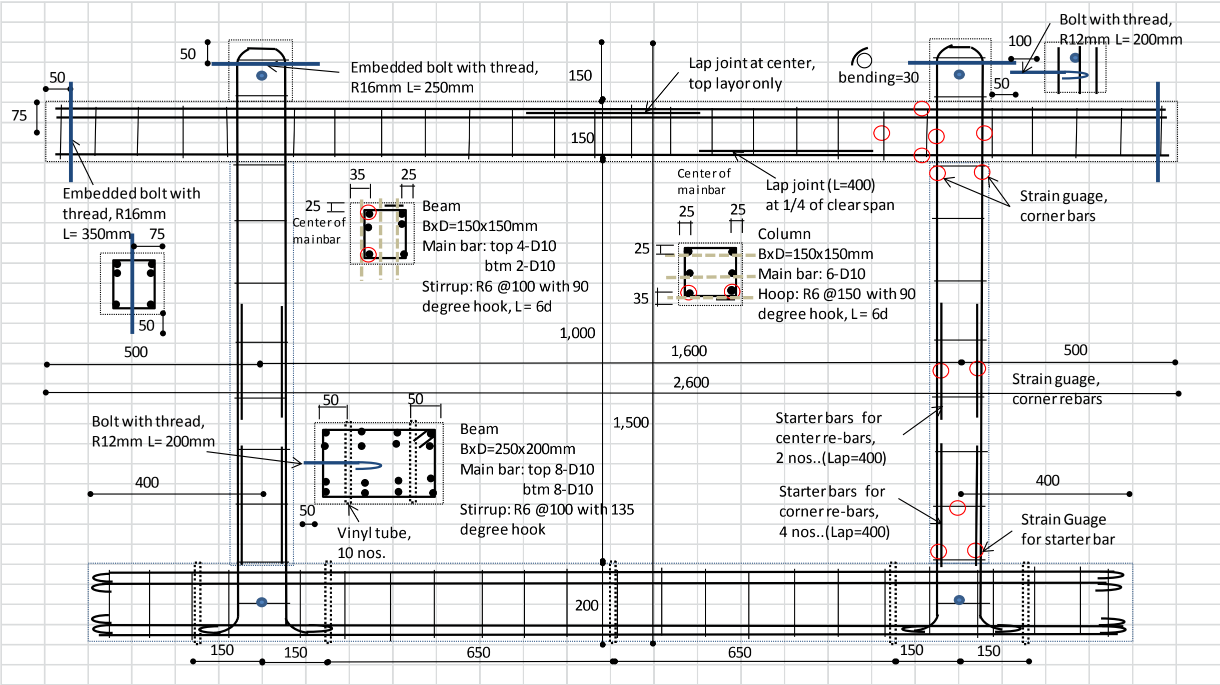
Type 2 (Standard beam and plain bar without lap joint) x 1



Type 2a (Standard beam and plain bar without lap joint) x1



Type 2b (Standard beam & deformed bar with lap joint) x 1



3.3 Load-deflection curve

Loading date of each specimen is shown as follows;

Specimen No.	Date	Remarks (observation during the loading)
1	5, 6 November 2012	Dial gauge (right upper for loading control) didn't work smoothly, within the range of 1mm.
2	10, 11, 12 November	Dial gauge (right upper for loading control) didn't work smoothly, within the range of 1mm.
6	14, 15 November	Embedded bolts hit measurement frame up to 4th cycle.
7	24 November	
5	18, 19, 29 November	
3	27, 28 November	
4	5 December	

Load-deflection curves by

①Displacement Transducer (DT) and load-cell, and

②Dial Gauge (DG) and load-cell are shown for each specimen.

and

③Hand written load-deflection curve is shown form next pages.

This hand written curve was prepared by the analogue load-meter of hydraulic jack and a dial gauge of upper right position during the loading. Specimen of No.1 of hand written is not accurate and is reference only.

As shown it is necessary to modify the data of DT (Data-logger) such as,

Points of missing data were connected by straight line intentionally. **Possible reason of missing data is that cables were not connected to data-logger properly**.

No1, data of DT is not continuous.

No.2, data of R=1/100 and 1/50 are missing.

Average of DT of left up and left down is shown. Other two DT are not working properly and are excluded.

No.5, data of DT is not continuous.

No.6, average of DT maybe not proper, since the vertical axis is not the center of curves.

Following story deflection angle R is numerical value of Dial gauge of right upper portion, divided by story height 1,150mm.

Result of specimen No.1

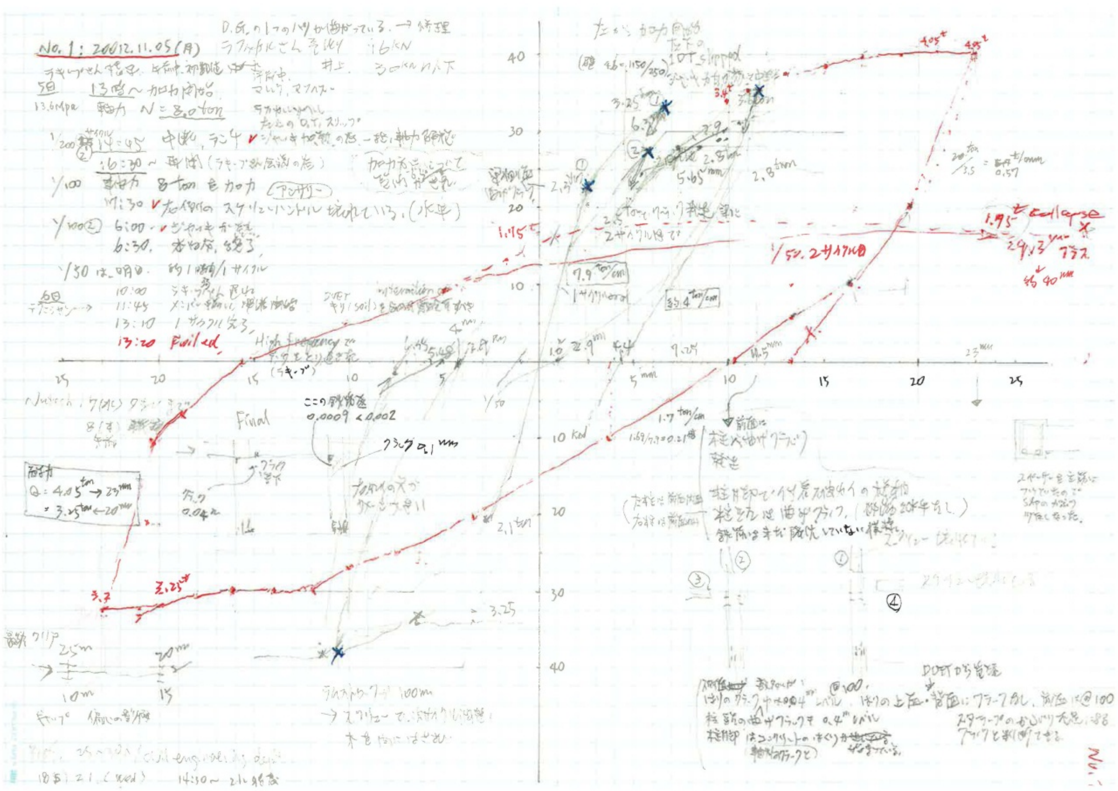
(Strong beam type, plain bar without lap joint for column, axial force ratio 0.215)

Axial force; 8ton(16.5Mpa concrete)

Behavior is similar to that of no.2. Out of plane behavior was observed at the bottom of columns.

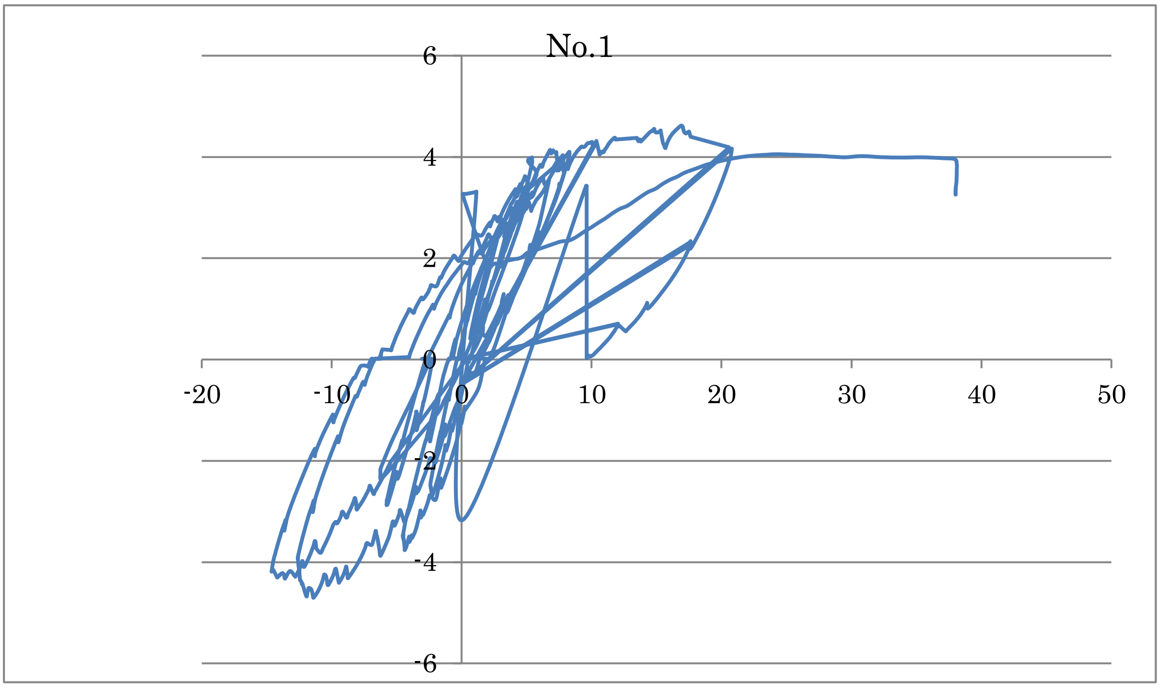
Unstable behavior that cannot control deflection was observed at the second loading cycle of R<1/50.

Following load-deflection curve is rough and is reference only.

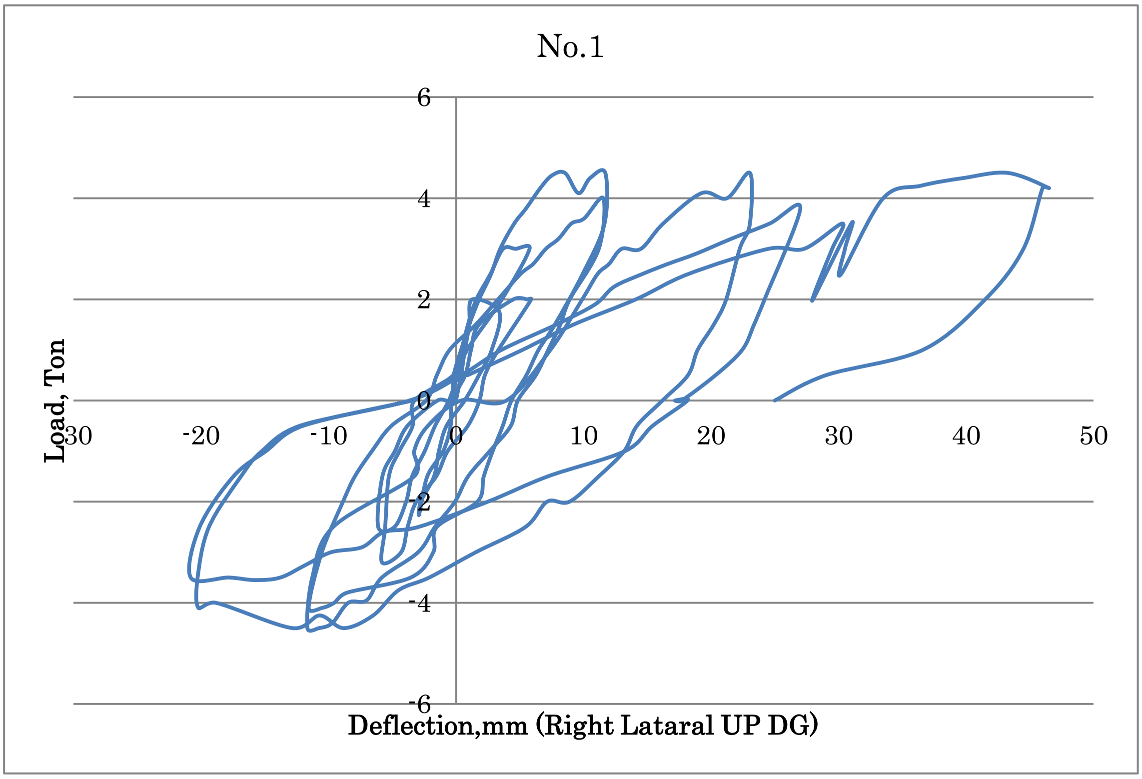


Preliminary Load-deflection curve 2013/02/28

No.1 DT, average of top 2 DT(column C and D, not C and E?) (left top and left down?)



No.1 Dial Gauge (Right top D.G.)



Result of specimen No.2

(Strong beam type, plain bar without lap joint for column, axial force ratio 0.32)

1/4 of capping concrete of top of left column was damaged by introducing axial force with 18 ton only, and then the axial force was reduced to 12 ton.

Behavior;

R(story deflection angle)= δ /h < 1/200, 3^{rd} cycle

Vertical cracks were observed at side of beam(this was caused by the shortage of concrete cover of stirrups), vertical and horizontal cracks were observed at the bottom of right column.

R <1/100(11.5mm), 5^{th} cycle

Flexural and shear cracks were observed on upper beam, vertical and horizontal cracks were observed at the bottom of columns, shear crack on top of column.

R <1/50(23.0mm), 6^{th} cycle

Compressive failure of covering concrete of top of column, split and detachment of concrete (by bond stress) at the bottom of column were observed.

Enlargement of crack at top of column and flexural cracks on beam, and compressive failure of covering concrete at the bottom of columns were observed.

R <1/25(46mm), 7^{th} cycle

Detachment of covering concrete at the top of column, and split of concrete at the bottom of column were enlarged.

Enlargement of flexural cracks on top of column, and compressive failure of covering concrete were observed.

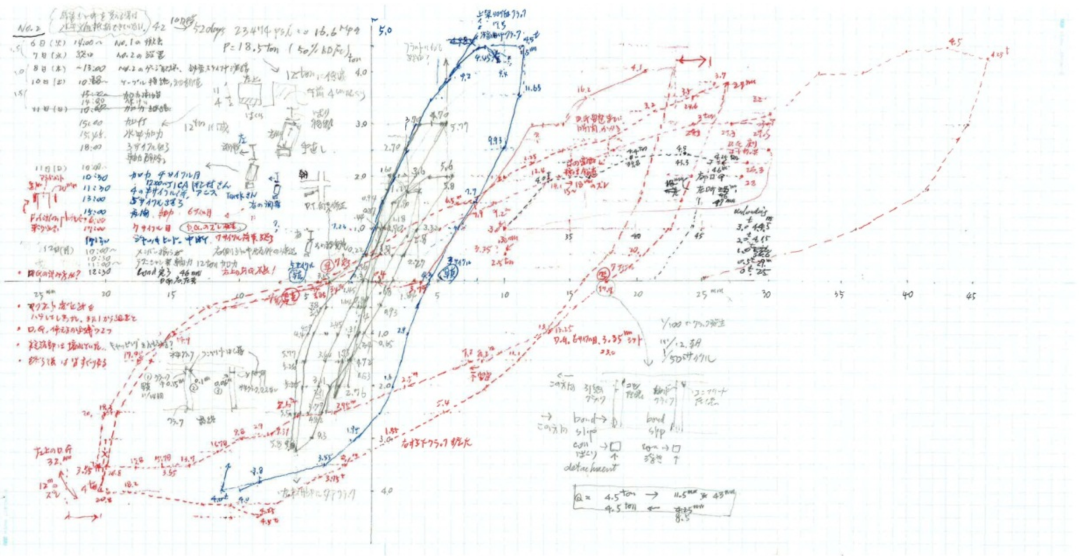
R<1/50, top and bottom of column

R<1/25, top and bottom of column

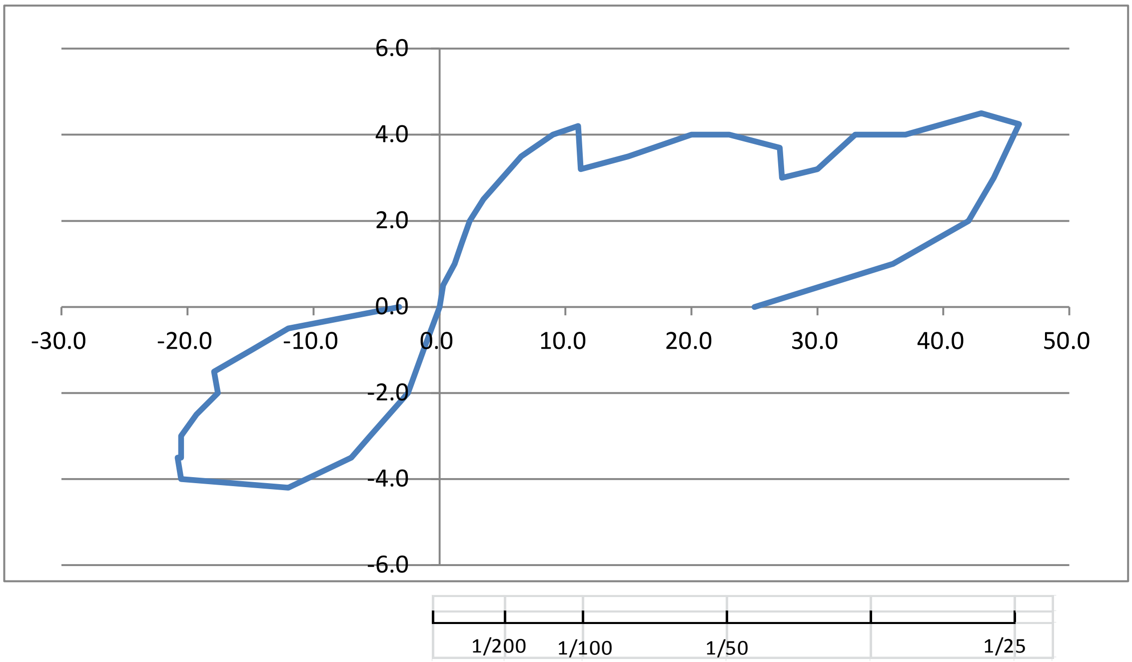
Collapse of column top caused by axial force was observed (after the test). Possible reason is that concrete was weak with honeycomb. This limited the size of vertical loading.

Load- deflection curve, specimen no.2

DG of right upper position was not work smoothly, this was found at later stage of the experiment.



No.2,

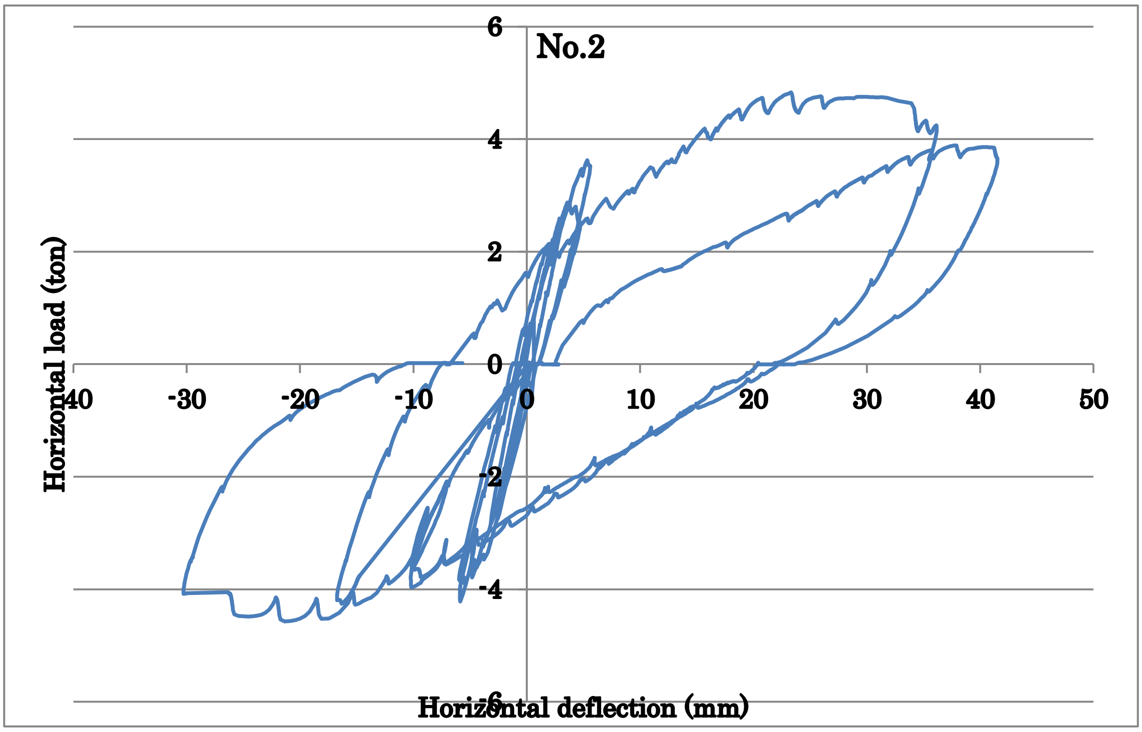


No.2 の加力制御に使った右上 D.G.はスムースに動いてなかったのが実験中に確認された。非対称となっているが、鉛直荷重の加力が偏心していた可能性がある。

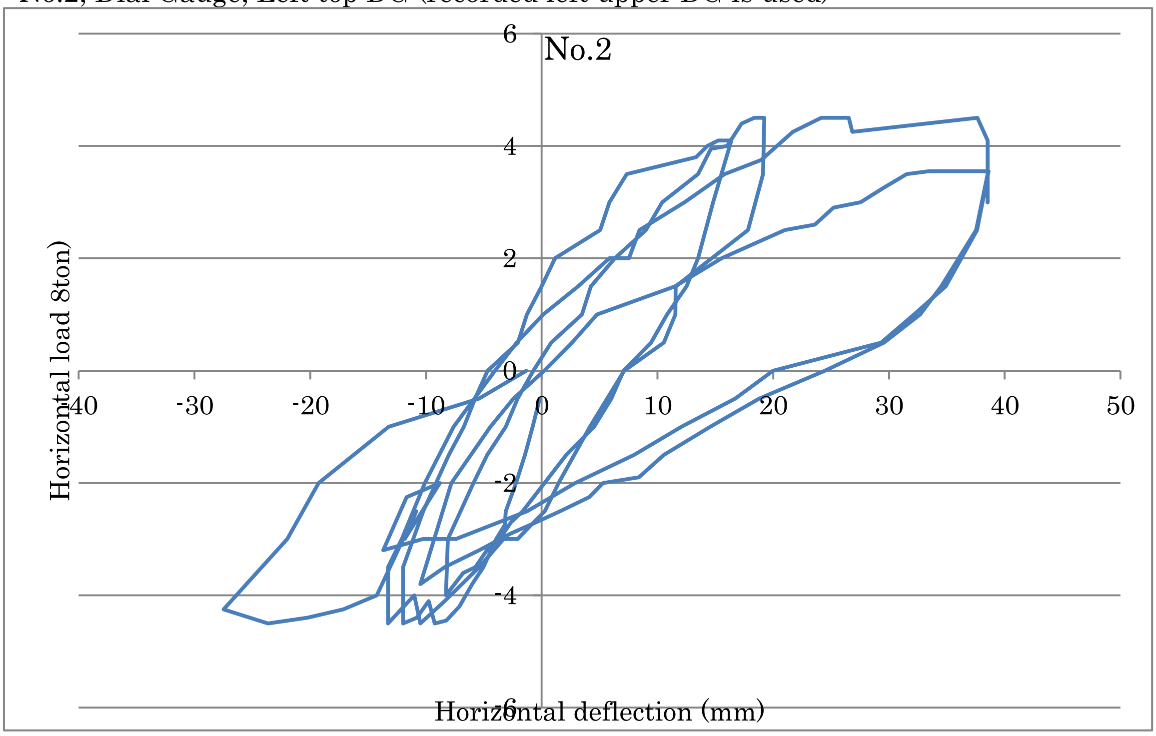
No.2

Deflection; Average of DT of left up and left down is shown. DT of right down was not working, max. more than 100mm), right up also not stable (not working at the beginning).

Data of loading cycle R=1/100 (11.5mm), R=1/50 (23mm) are missing.



No.2, Dial Gauge, Left top DG (recorded left upper DG is used)



No.2 の DT は、左上と右上の平均を表示している。右上は不安定（開始時点で動いていなかった）、右下も 100mm を超えた数値が出ており適切に動いていなかった。

R=1/100、R=1/50 の DT のﾃﾞｰﾀが欠如している。

Specimen, No.3

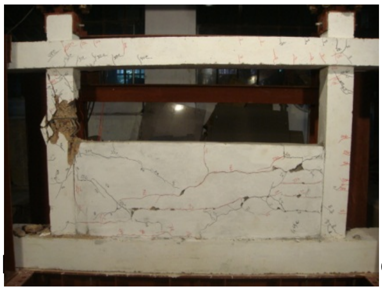
(strong beam, lap joint of plain bar without hook for column, axial force ratio 0.43, with brick wall), loading on 2012/11/27~28

Height of brick standing wall is half of clear height of column (beam to beam) and thickness is 115mm.

Maximum strength; positive direction Q=7.25ton (δ =10.8mm)

Negative direction Q=6.8ton(δ =11.58mm), average is 7.03ton.

Shear failure occurred at left side column (loading was provided from left to right first). Shear (diagonal) cracks were observed at right column but no serious damage was observed, when left column failed.



e test

Behavior of left column is shown below:

(a) R<1/200 (b) R<1/50 (c) R<1/50 (d) R<1/50

Figure2.3.2. Behavior of left column

(R; story deflection angle = story deflection/ story height)

R<1/400 (δ < 2.88mm), 1st cycle, crack on finishing mortal observed. Max. load is 4.9 ton in positive loading.

R<1/200 (δ < 5.75mm), 2nd cycle, two shear cracks were observed on left column. Max. positive load is 6.5 ton. Refer to above figure (a).

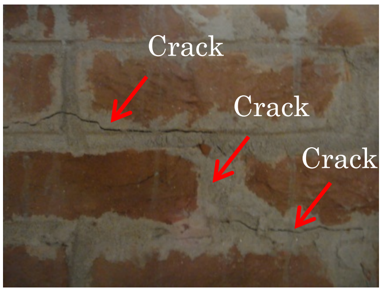
R<1/100 (δ < 11.5mm)**,** 3rd cycle, max. load is 7.25ton for positive loading and 6.8 ton for negative loading.

R<1/50 (23.5mm), 5th cycle, max. load is 6.7 ton for positive loading and 5.7 ton for negative loading.

R<1/50 (23.5mm), 6th cycle, shear failure of column occurred at 2nd positive cycle, at 4.7 ton /16.2mm, and the load of 4.7 ton reduced to 3.5 ton/ 22.5mm after shear failure. Refer to above figure (b).

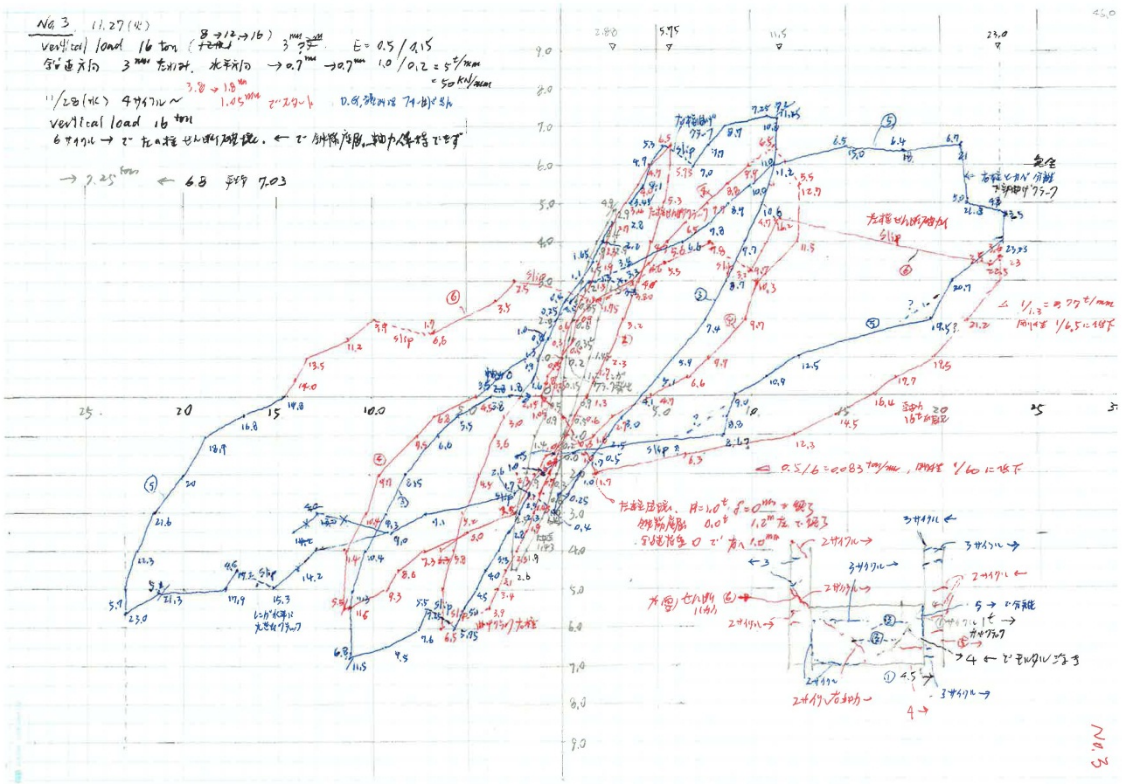
R<1/50 (23.5mm), 6th cycle, detachment of covering concrete at2nd negative cycle, buckling of main re-bar occurred at δ 1.7mm/ 2.0 ton of negative loading, vertical load carrying capacity reduced, and vertical load was released to zero. Refer to above figure (c) and (d).

Buckling of main re-bar



Cracks of joint mortar of brick standing wall (rear side)

No. 3, load- deflection curve (reading value of hydraulic jacks and a dial gauge)



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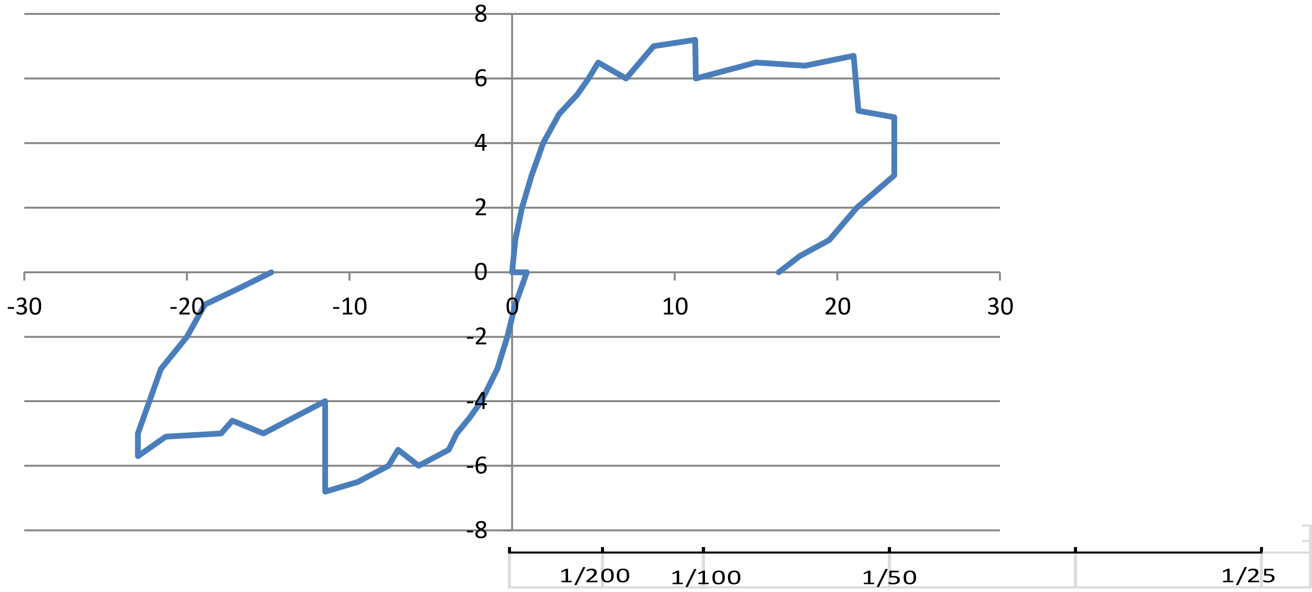
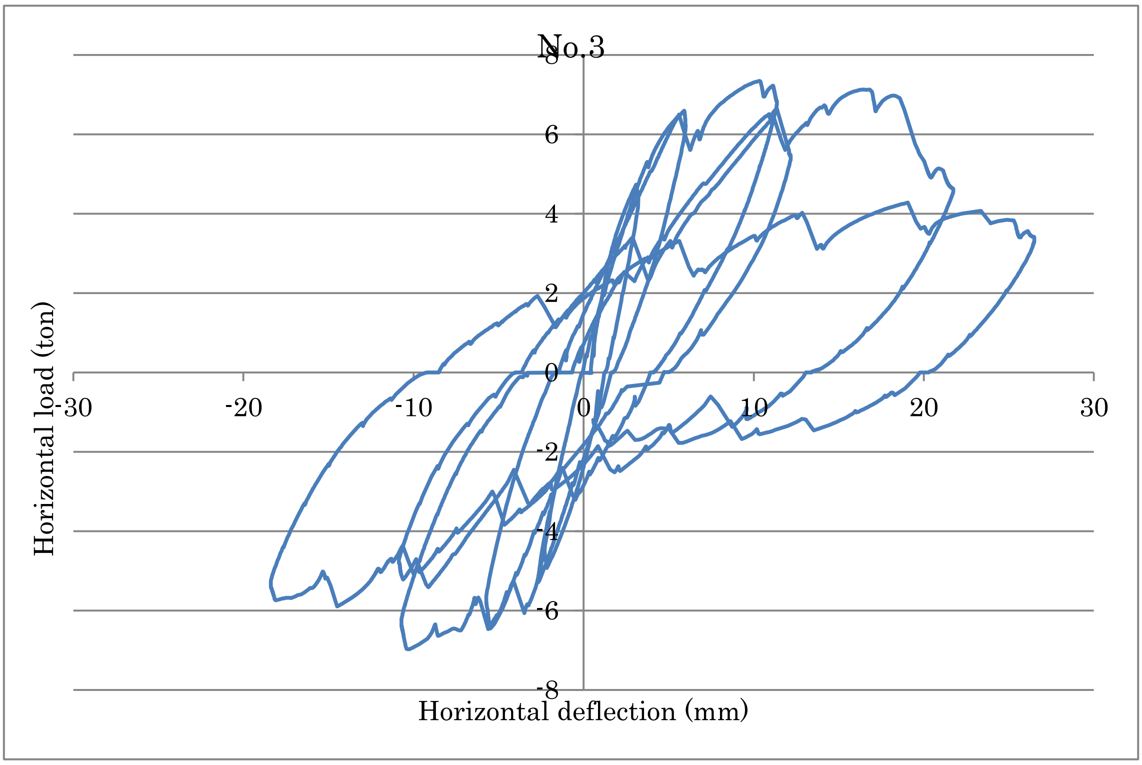
No.3, Simplified load-deflection curve covering peak values (vertical axis; ton, horizontal axis; mm)

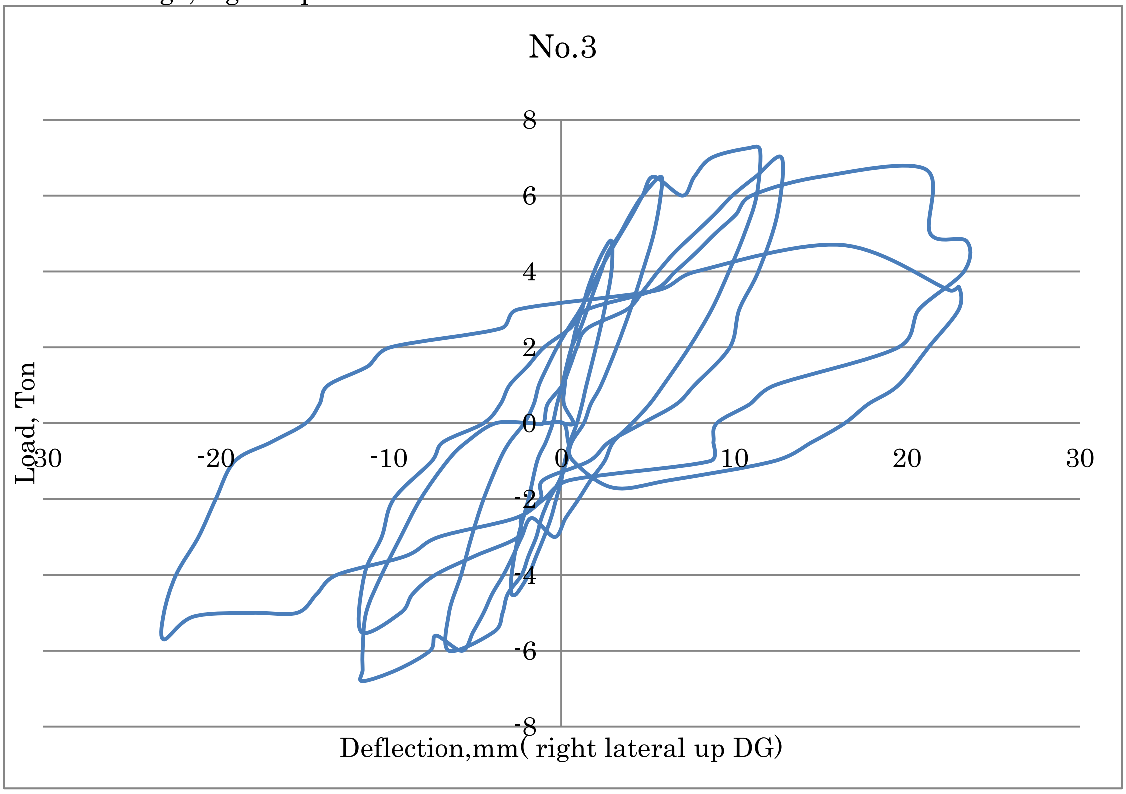


No.3

Deflection; average of 4 DT



No.3 Dial Gauge, right top DG



<u>Specimen No.4</u> (Strong beam, plain main bar with lap joint, brick wall with thickness equivalent to single layer, axial force ratio of column 0.43), loading on 5 December2012.

Height of brick standing wall is 3/4 of clear height (top of beam to beam dimension), 760mm. thickness of wall is 60mm including mortar, and 50~55mm excluding finishing mortar, which is 0.4 times column width.

Initial stiffness ; 1.0ton/0.2mm=5 .0 ton/mm

R (story deflection angle = story deflection/ story height)= δ /h **< 1/400**, 1st cycle, δ <2.88mm

Two diagonal cracks (shear cracks) were observed on top of left column at 1st positive loading. Cracks on standing wall observed.

R<1/200 (δ < 5.75mm), 2nd cycle,

Detachment of finishing mortar on brick standing wall started.

R<1/100 (δ <11.5mm), 3rd, 4th cycle,

Vertical crack occurred at lower part of left column at positive loading. Diagonal cracks (shear cracks) were observed on top of right column at positive and negative loading. Flexural cracks at the bottom of right column.

R<1/50 (δ <23mm), 5th cycle.

Compressive failure of covering concrete at external side of left column started。 Enlargement of vertical crack on left column was observed at negative loading.

R<1/50 (δ <23mm), 6th cycle.

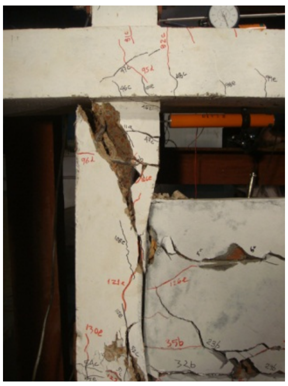
Shear failure of left column occurred during positive loading at deflection angle 1/100, with loading of 4 ton. Brick standing wall was almost collapsed with upward movement at the center.



R<1/25 (δ <46mm) , 7th cycle,

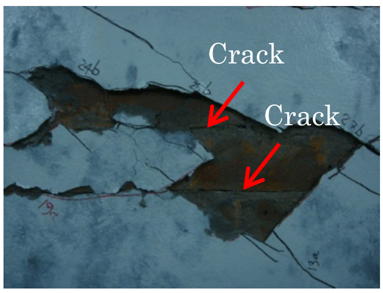
Vertical load carrying capacity of left column reduced from 16ton to 8 ton at horizontal deflection of 30mm and horizontal load 3.5 ton. Vertical load was release ton zero at 35mm/ 2.0ton. Shear cracks were observed for right column but no shear failure was observed.





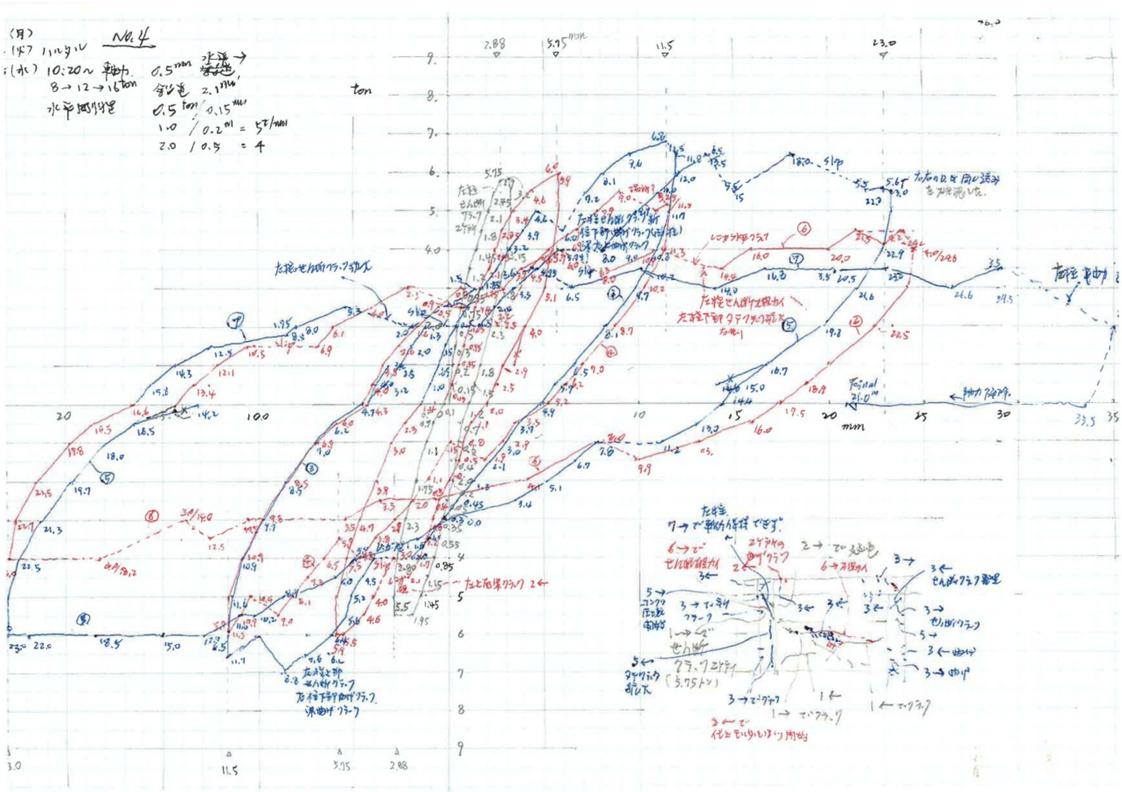
Upper of left column

lower of left column

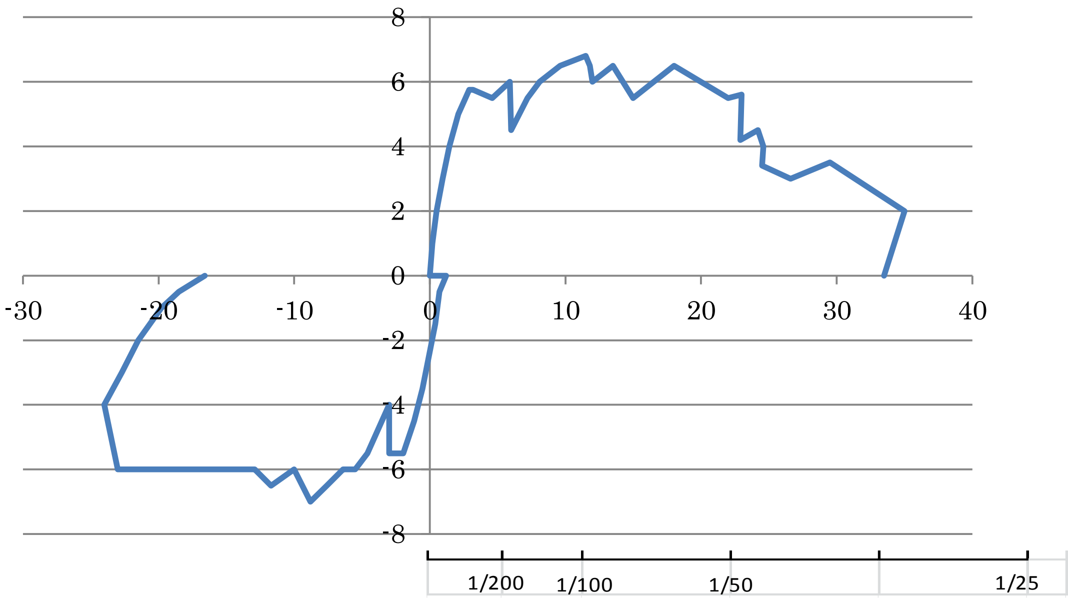


Horizontal crack of mortar joints

No. 4, load- deflection curve (reading value of hydraulic jacks and dial gauge)

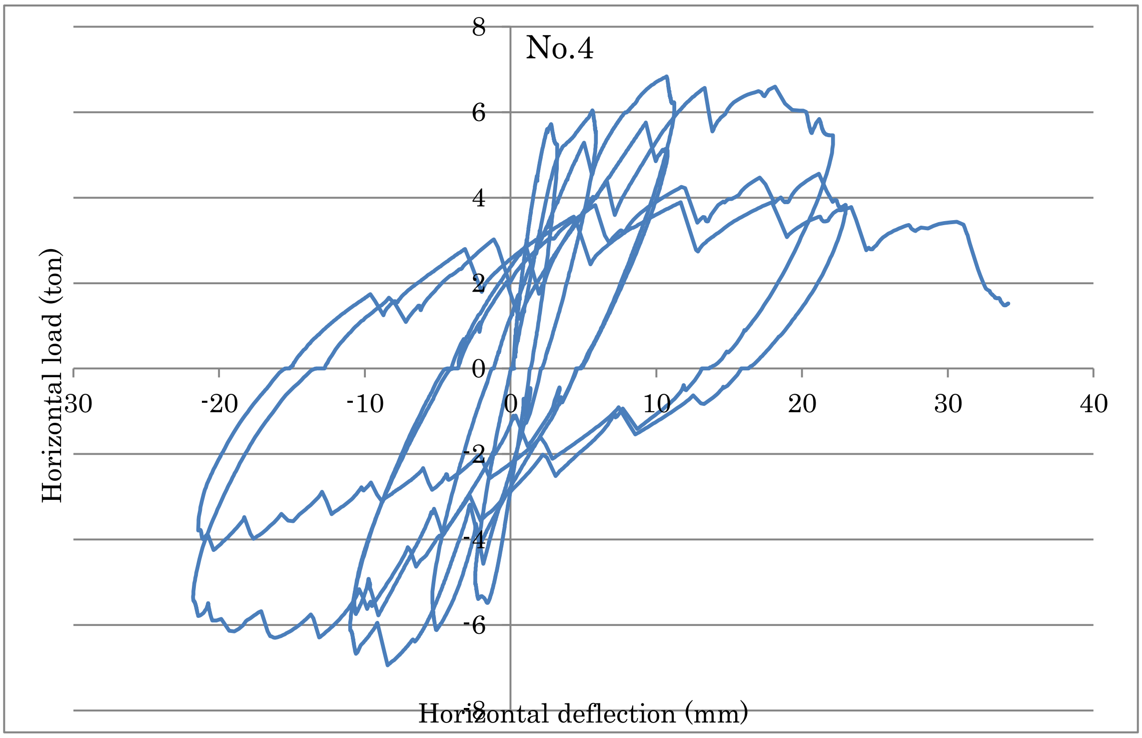


No.4, simplified load-deflection curve covering peak values (vertical load, ton, horizontal axis, mm)

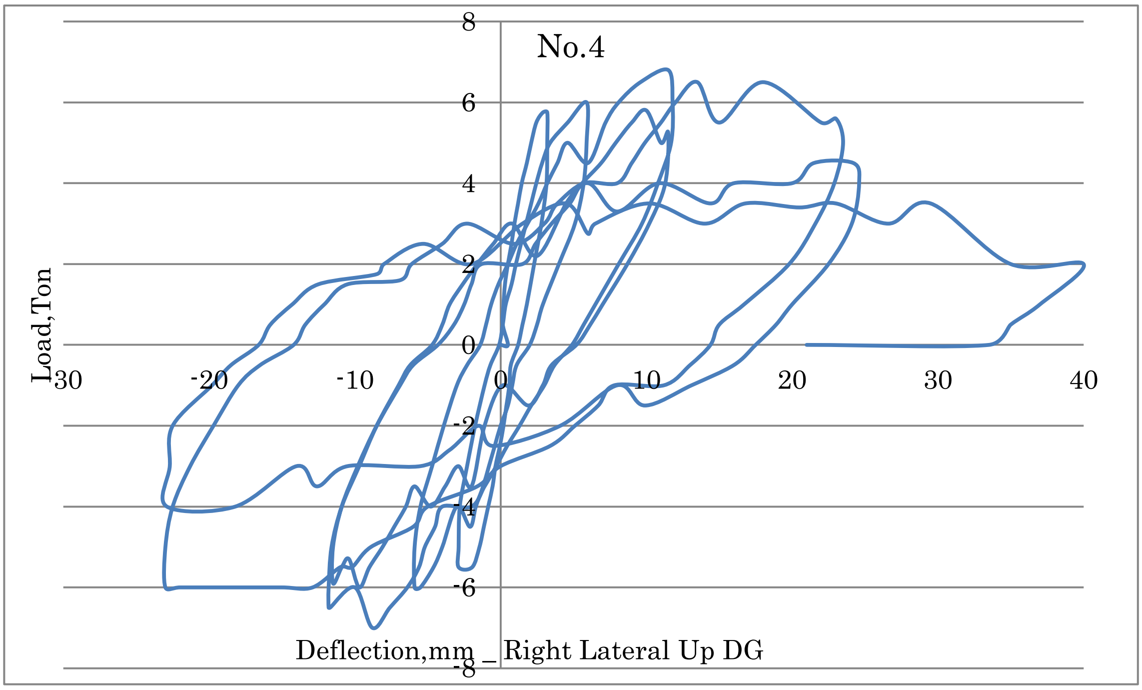


No.4

Deflection; average of 4 no's DT



Dial gauge, right top DG



Specimen No.5

(standard beam, plain main bar with lap joint, axial force ratio 0.43)

It is supposed that concrete strength of specimen no. 5 was high. If the concrete strength is Fc=18.3Mpa, then axial force ratio (N/bdFc) is 0.389. This will help to increase the ductility related to the axial force ratio in spite of original plan of the experiment.

Behavior

R (story deflection angle = story deflection/ story height)= δ /h **< 1/200**, δ <5.75mm ,2nd cycle, Flexural cracks on beam, shear crack on the left side of beam, bottom of left column observed.

R <1/100(δ <11.5mm), 4th cycle

Increase of flexural cracks on beam, shear crack on the left side of beam, bottom of left column observed. Vertical crack at the bottom of column, diagonal crack of left panel area (beam column joint), diagonal crack at the bottom of column were observed.

R <1/50(δ <23.0mm), 6th cycle

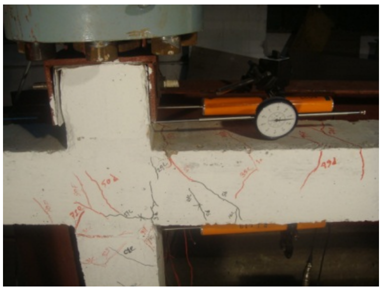
Diagonal crack at the top of column, diagonal crack at the top of column and panel area, flexural crack at the top of right column, diagonal crack at the bottom of column were observed. Failure of covering concrete at the bottom of column started.

R <1/25(δ <46mm), 7th cycle

Detachment of covering concrete at the bottom of column, extension of split (vertical) crack at the bottom of column, compressive failure of covering concrete, enlargement of flexural crack and shear crack at the top of column, extension of flexural crack on beam were observed.

Figures are shown below.

R<1/25

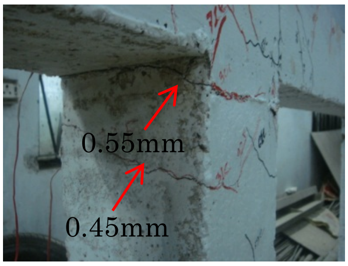


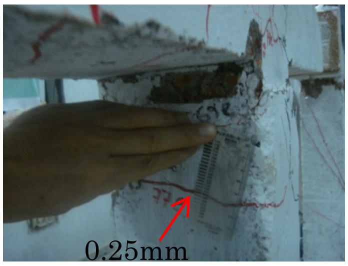


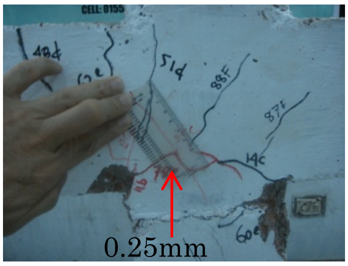
Specimen No.5, Concrete cracks and failure of covering concrete

Cracks above beam, crack width on left side is big, but right side is small.

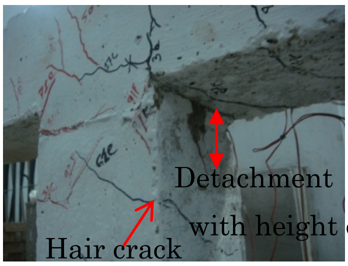
Crack beneath beam, left side is 0.15mm, and right side is small.



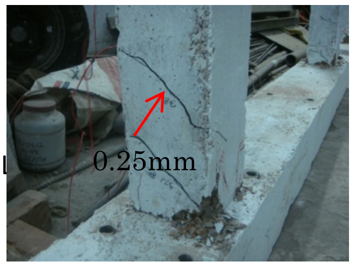


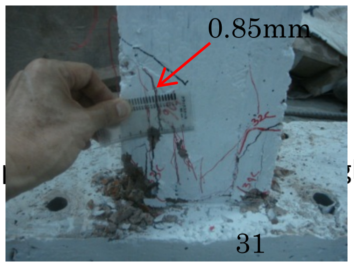


Left column, cracks on upper part Right column, cracks on upper part and panel area, 0.25mm

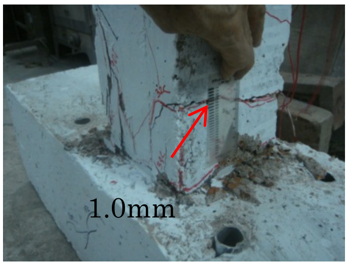


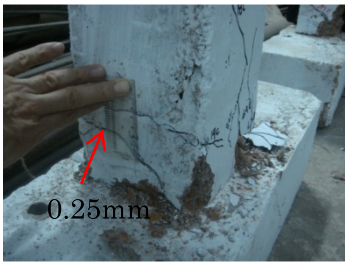
Left column, compressive failure at the top Right column, detachment and compressive failure





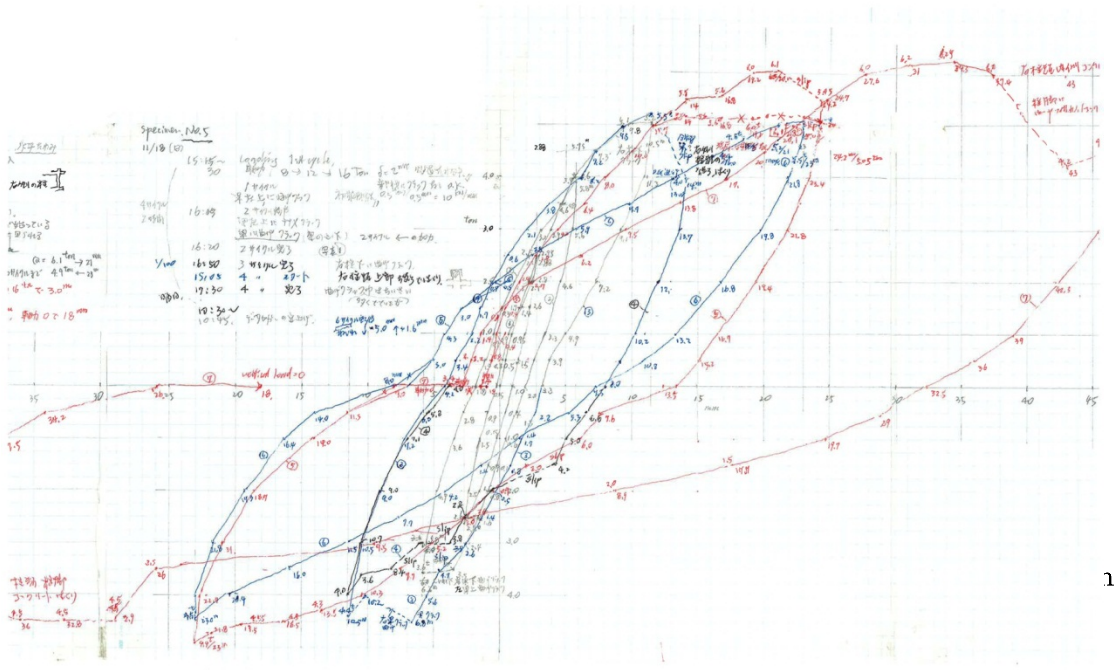
L la ght colur



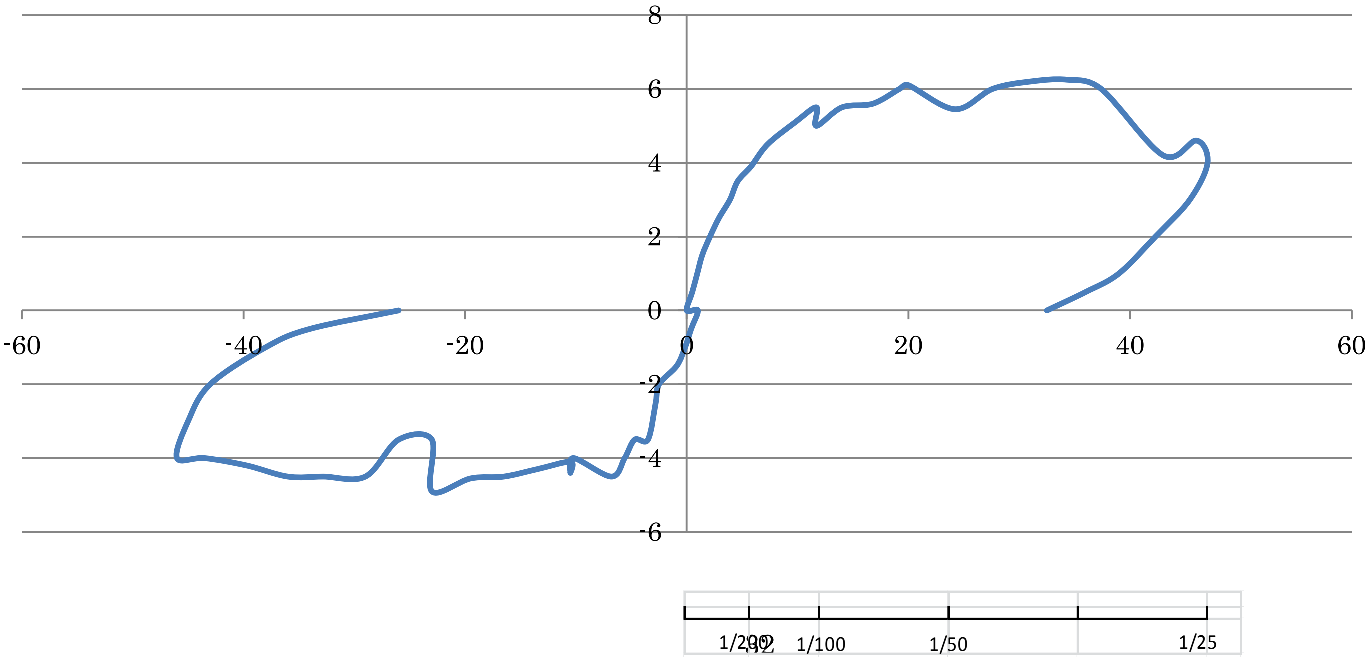


Left column, flexural crack 1.0mm Right column, flexural crack0.25mm and compressive failure

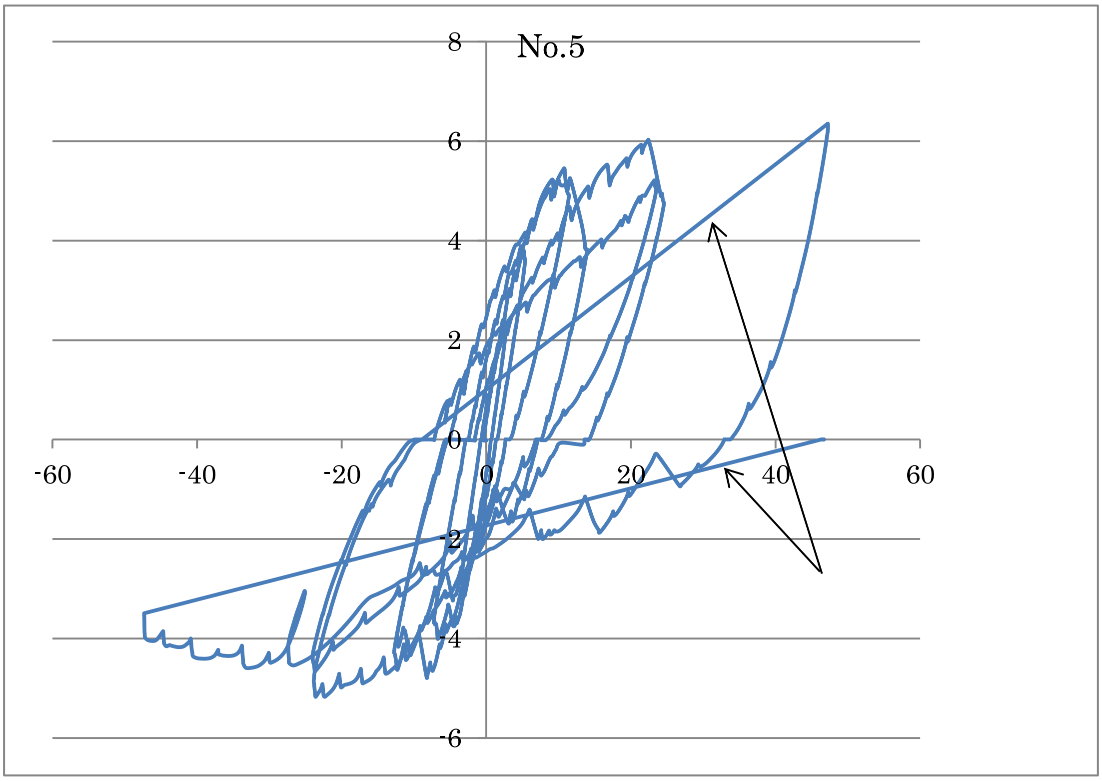
No. 5, load- deflection curve (reading value of hydraulic jacks and dial gauge)



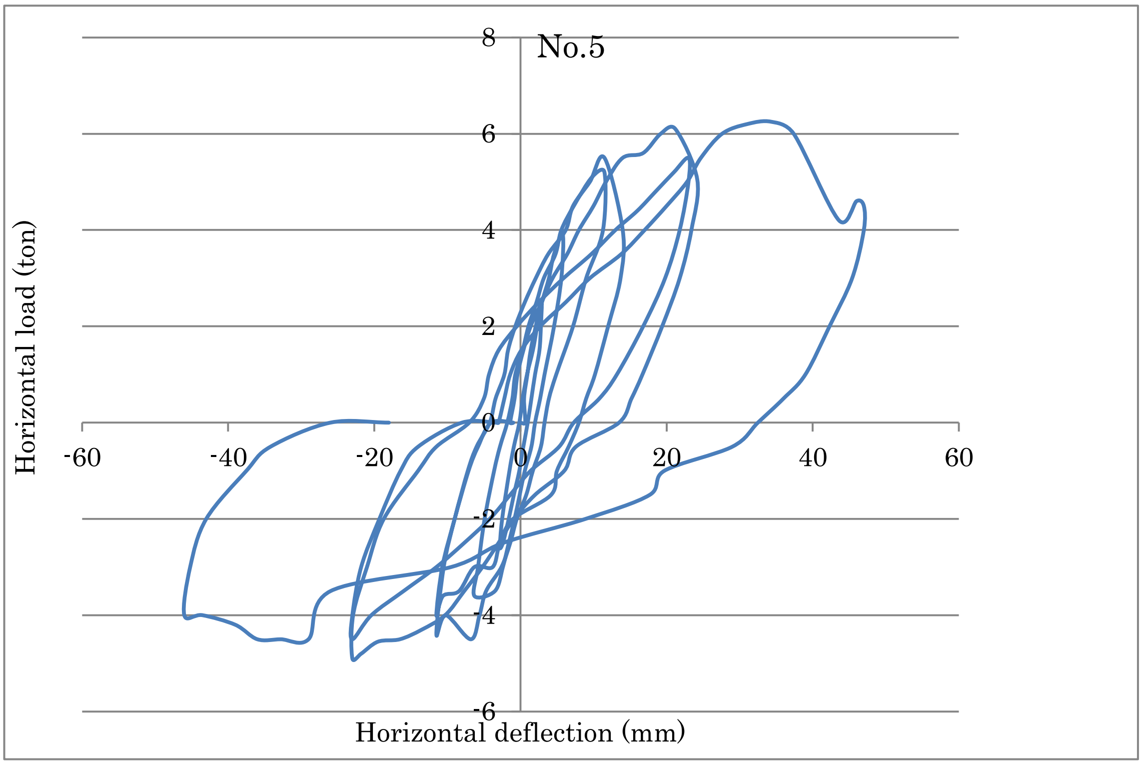
No.5, Simplified load-deflection curve covering peak values (vertical load; ton, horizontal axis; mm)



No.5 Average of top 2 DT, gap of data at raw 12,094, data till 13,281 are used?



No.5, Dial gauge (right up DG) -hydraulic jack



<u>**Specimen No.6**</u> (Standard beam, plain main-bar without lap joint, axial force ratio 0.43)

Behavior

R (story deflection angle = story deflection/ story height)= δ /h **< 1/200**, δ <5.75mm ,2nd cycle,

Flexural cracks on side of beam, (main reason will be shortage of concrete cover of stirrups).

R < 1/100 (δ < 11.5mm), 4th cycle

Flexural cracks and shear crack on beam, vertical crack at the bottom of column observed.

R<1/50 (δ < 23.0mm), 6th cycle

Compressive failure of covering concrete at the top of column started, enlargement of flexural crack on top of concrete and beam, compressive failure at the bottom of left column and right column.

R <1/25 (δ < 46mm), 7th cycle

Detachment of covering concrete at top of column, enlargement of split crack at the bottom of column, enlargement of flexural crack at the top of column, compressive failure of covering concrete at the top of column.

After R=1/100, 4th cycle and R=1/50, 6th cycle, bottom of left column



After R=1/25, 7th cycle



shear crack, width 1.2mm

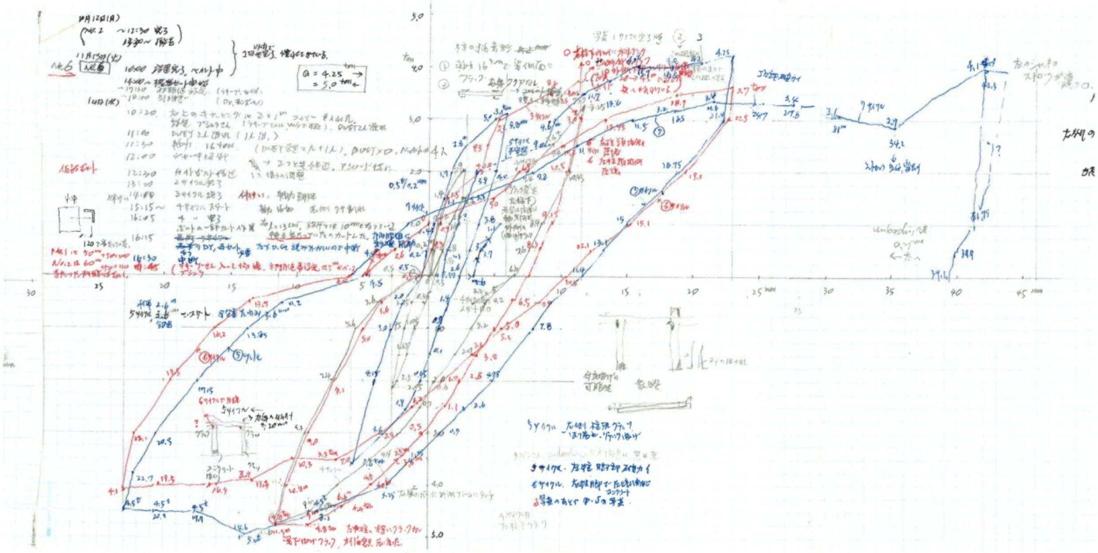
Detachment of covering concrete

Bottom of left column(force toward out of plane?)

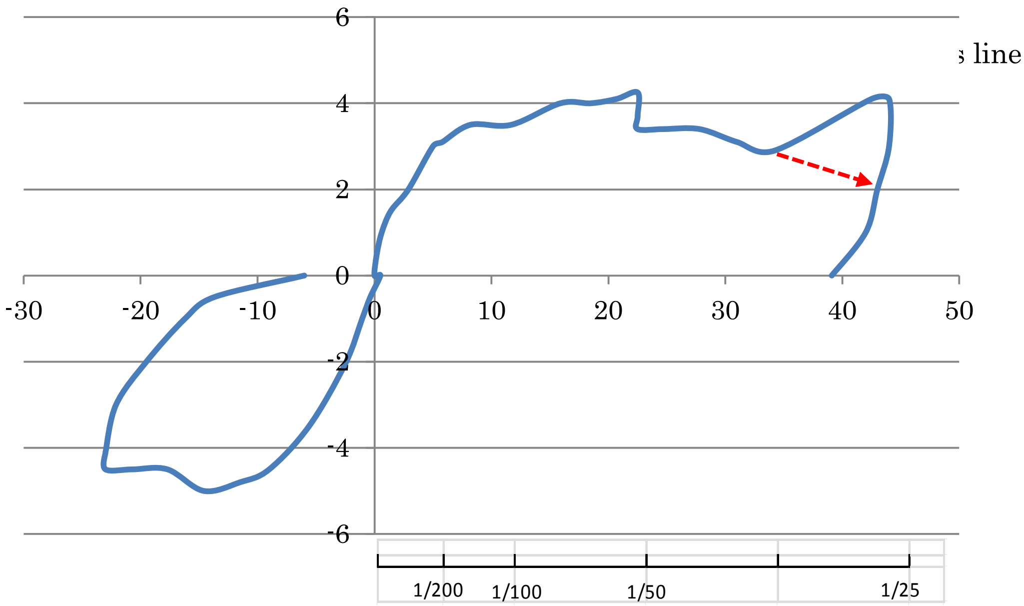
Compressive failure of covering concrete


bottom of right column

No. 6, load- deflection curve (reading value of hydraulic jacks and dial gauge)

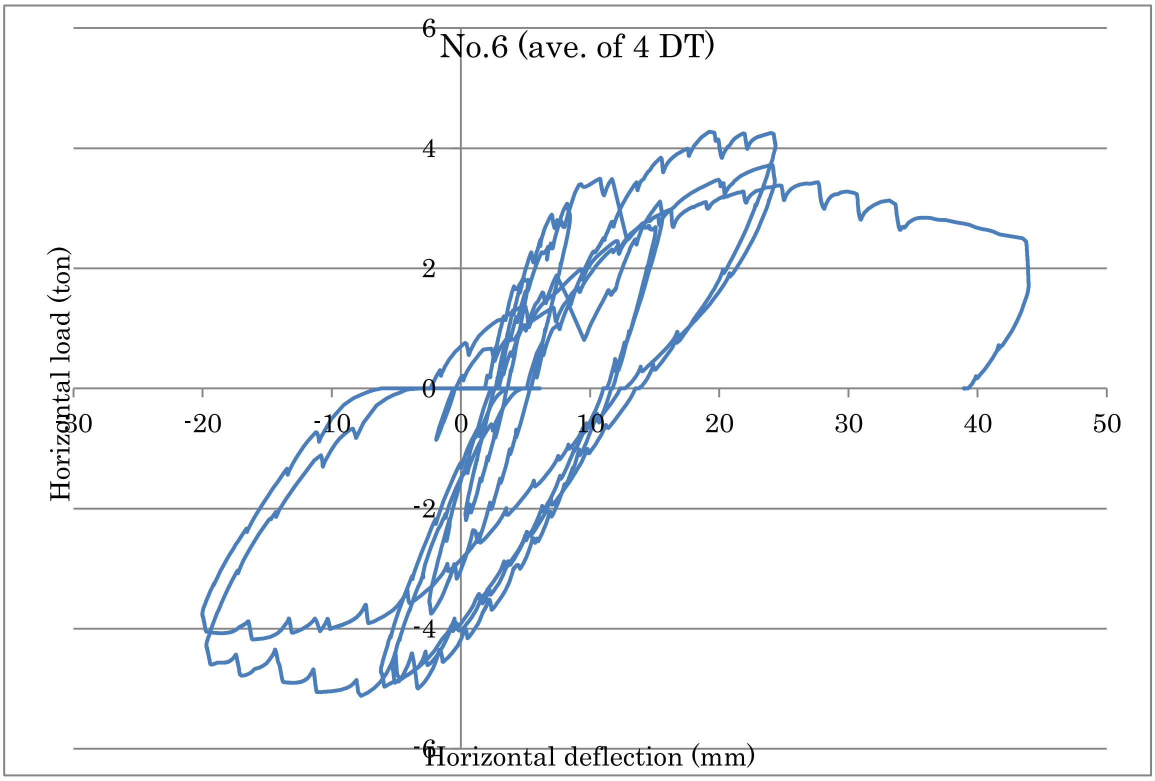


No.6 n)

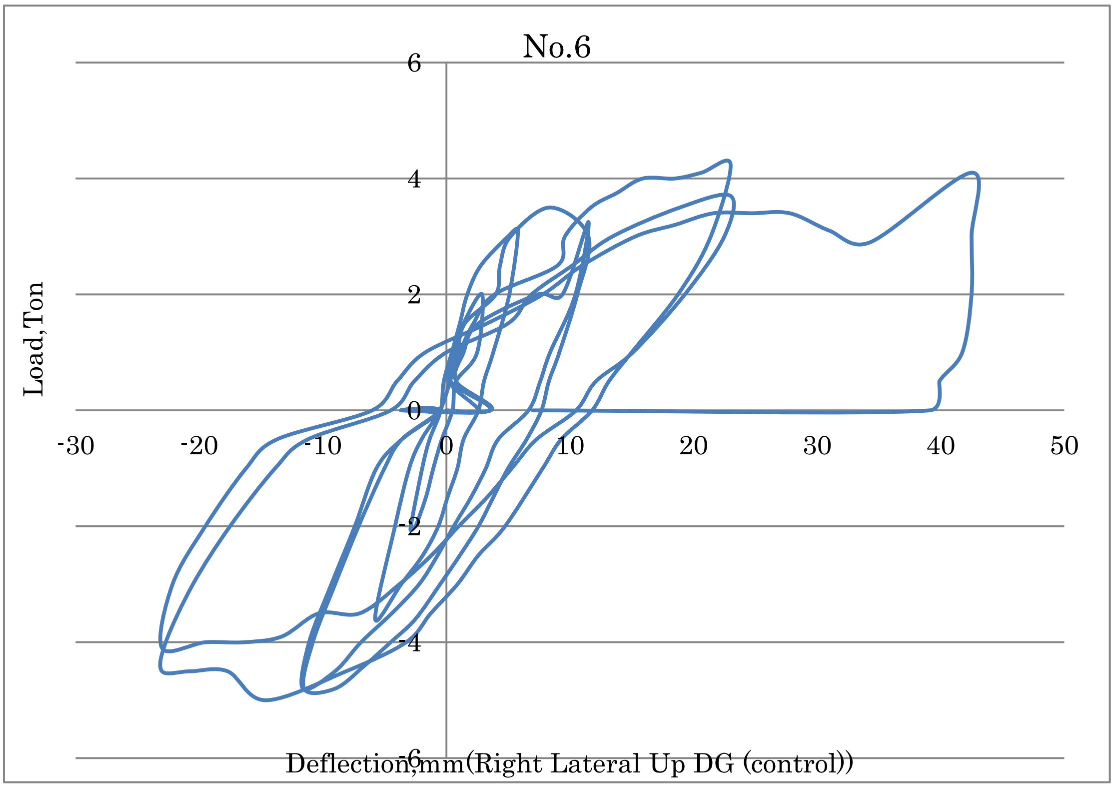


No.6 は、仮設の埋め込みボルトの長さが長く、計測フレームに 4 サイクルまで接触していた。ボルトをカットした際に計測フレームに振動が生じ、DT、DG の位置がずれ再セットした。

No.6 Average of top 4 DT, center line (vertical axis) moved to left side.



No.6, Dial Gauge (Right up DG)



Specimen No.7 (Standard beam, deformed main bar with lap joints, axial force ratio 0.43)

Initial stiffness

0.5ton/0.4mm=1.25ton/mm=12.5kN/mm

Maximum strength Positive Q=5.0 ton

Negative Q=5.25 ton

Behavior

R (story deflection angle)= δ /h **< 1/200**

Cracks on side of beam (main reason will be no concrete cover for stirrups)

R <1/100, (11.5mm)

Flexural cracks on beam.

R <1/50, (23.0mm)

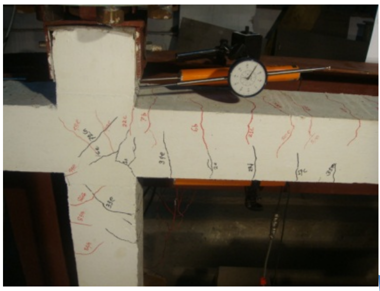
Flexural cracks on top and bottom of columns, compressive failure for covering concrete at column.

R<1/25, (46mm)

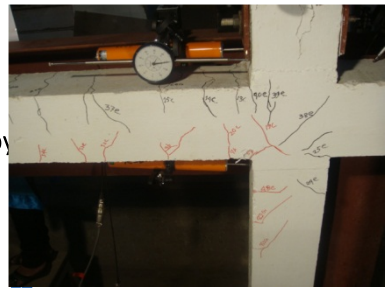
Detachment of concrete at bottom of column, enlargement of concrete split at the bottom of column, enlargement of flexural cracks at top of column, compressive failure of covering concrete at the bottom of column.

Movement towards out of plane was 10~15mm.

Specimen after the R<1/25 (46mm), detachment of covering concrete at the bottom of column, split failure at the column.



Crack at side of wall caused by

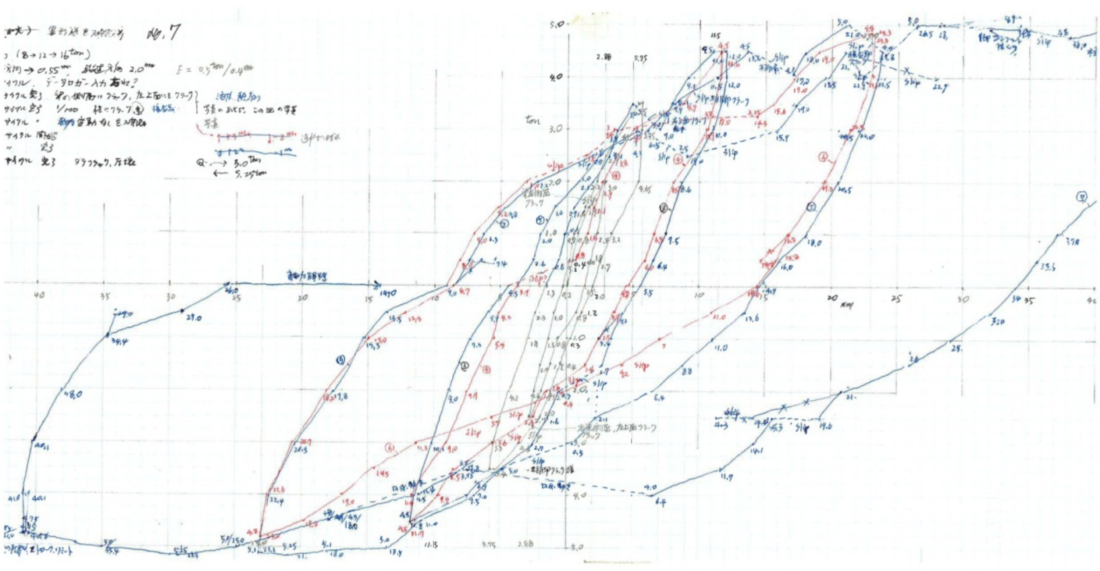


Flexural crack on beam, shear crack at panel area

Compressive failure of covering concrete

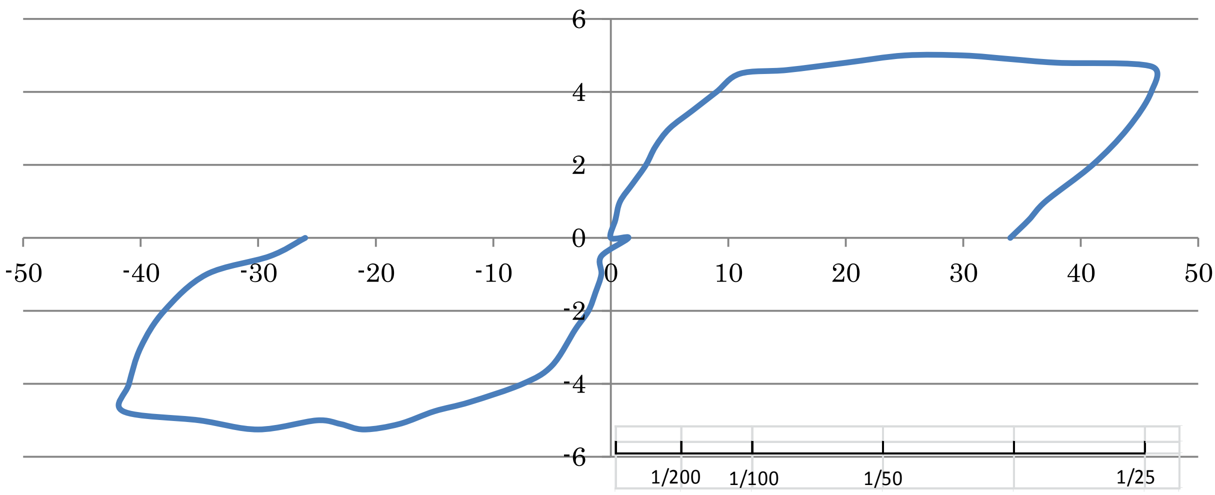
Compressive failure of covering concrete and split (vertical crack) failure

No. 7, load- deflection curve (reading value of hydraulic jacks and dial gauge)

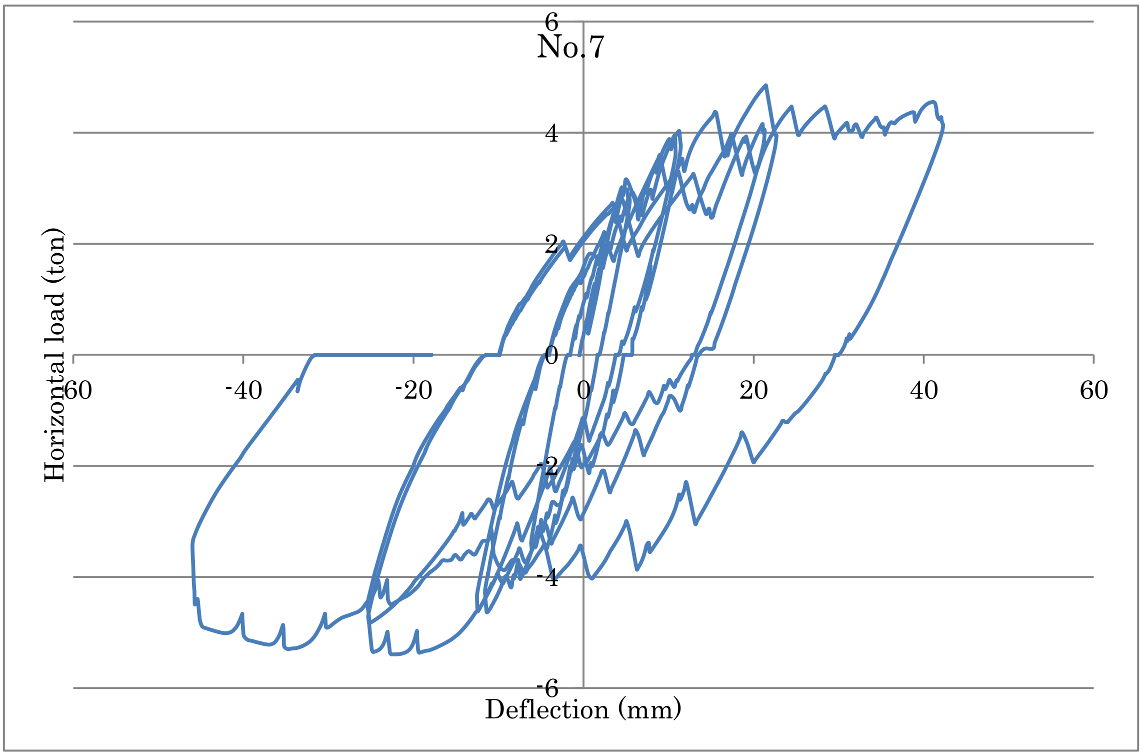


ion

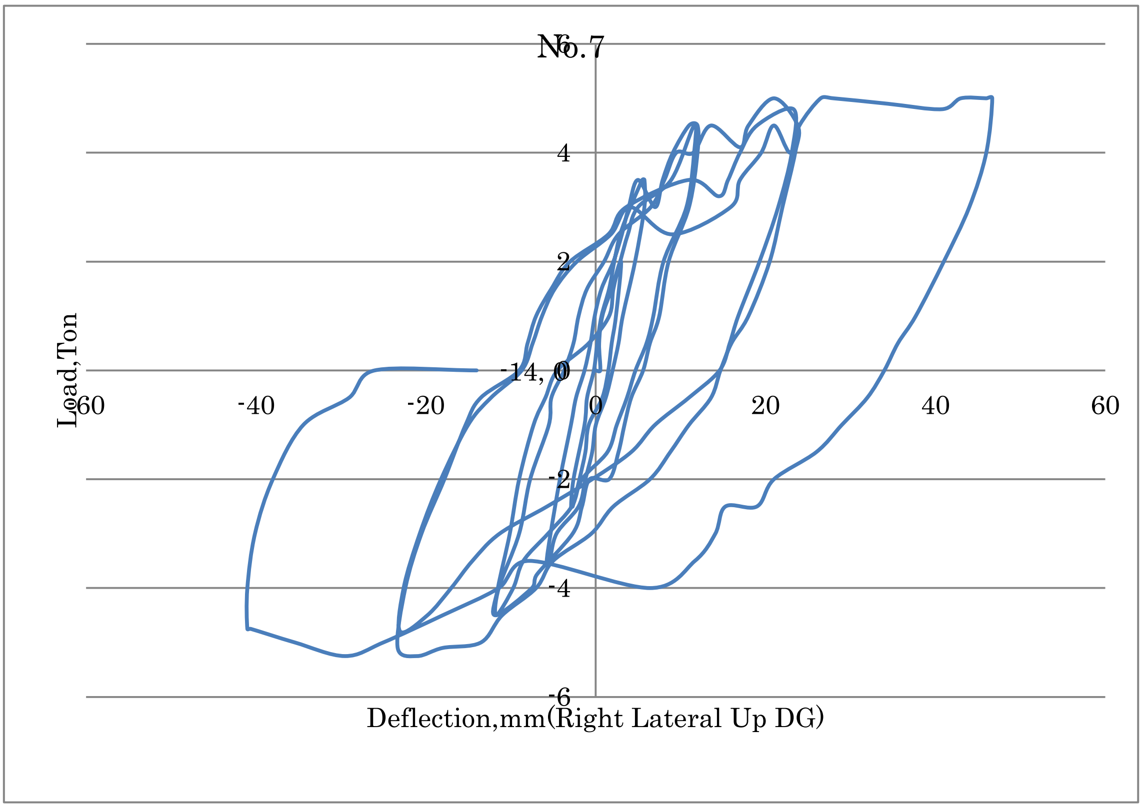
No.7, Simplified Load-deflection curve covering peak values (vertical load; ton, horizontal axis; mm)



No.7, Average of top 2 DT



No.7, Dial Gauge, right up DG



3.4 Material Test

1) Concrete; Specified concrete strength: 12Mpa (12N/mm2)

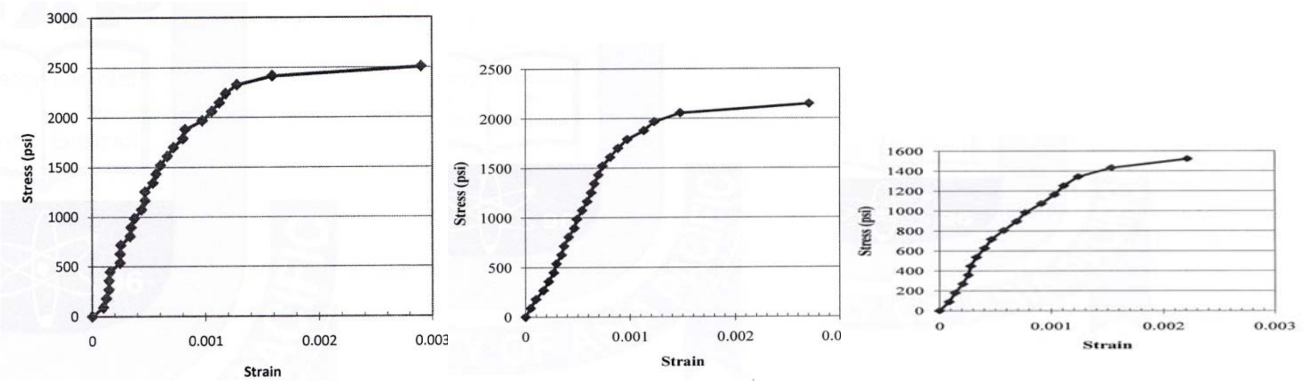
Design mix

Following trial mix was proposed for 28-day compressive strength of concrete from 1500 psi (10.3N/mm2) to 2000 psi (13.8N/mm2). 1psi = 0.06895n/mm2

Mix No.	Maximum Aggregate Size (mm)	W/C	Sand to aggregate absolute volume ratio	Cement Content (kg/m^3)	Water Content (kg/m^3)	Fine Aggregate Content (kg/m^3)	Coarse Aggregate Content (kg/m^3)	Volumetric Ratio*
1	10	0.65	0.44	260	169	831	814	1:3:3.3
2	10	0.70	0.44	260	182	816	800	1:2.9:3.3
3	10	0.75	0.44	260	195	802	785	1:2.9:3.3

Slump = 100 mm to 175 mm, * Amount of water is to be varied as per specified W/C.

Stress strain relation of 3 types by UAP is shown below.



Mix No. 3 was selected to get concrete strength 11~12Mpa.

But actual concrete strength of specimens was <u>15Mpa for 28 days</u> and <u>16.5Mpa for 56 days</u>. Main cause of the increase of concrete strength is considered as out of control of water contents of fine aggregate and course aggregate.

Results of concrete strength test

Concrete (Unit: N/mm2) average of three molds

No. of Specimen	Casted date	7days	28days	42days	56days
1, 2	14-Sep	12.0	13.6	**	16.6
5, 6	19-Sep	9.2	**	15.3	16.5
3, 4& 7	25-Sep	9.1	16.5	**	16.1

Schmitt hammer test, result by the formula of Architectural Institute of Japan

Average of 20~40 x 5 times measurements were done at the lower beam, unit; Mpa (N/mm2)

	No.1	No.2	No.3	No.4	No.5	No.6	No.7
Strength	14.9	16.4	16.0	(20.3)	18.3	16.9	16.5

Concrete strength of no.5 is higher than the average and strength of no.1 is lower than the average. Strength of no.4 is measures with the condition of fixing with foundation beam with bolts. No. 3 is measured with horizontal position of the specimen. Others were measures from the side for the lower beam with standing position of specimens.

Cement mortar strength test

Mortar strength for brick standing wall

30Mpa (30days, cylinder equivalent)

5707, 5351, 5024Mpa (Cube) is converted to cylinder, and average is 4,370Mpa (30Mpa, 307kg/cm2)

2) Reinforcing bar 2013/03/04, revised on 03/11

1) Summary of re-bar test in Japan using Bangladesh made re-bar

Re-bar tests of Bangladesh made used for the structural test are summarized as follows.

Re-bars(Unit: N/mm2)、Specified yield stress of re-bar: 275Mpa (275N/mm2)

Case 1(BUET), yield stress (N/mm2) only shown, there are 5 universal machines at the lab.

	Plain bar 10mm	Plain bar 6mm	Deformed bar 10mm
1	445	490	400
2	480	475	390
3	470	940	390
Average	**465** N/mm2	**635** (**482**ave. of 1,2)	**396** N/mm2

Note; Ave. Young's modulus was 2.0x10^5Mpa.

Case 2 (UAP), yield stress (N/mm2) only shown,

	Plain bar 10mm	Plain bar 6mm	Deformed bar 10mm
1	544	297	284
2	284	303	284
3	393	303	284
Average	**407** N/mm2	**301** N/mm2	**284** N/mm2

Note; Yong's modulus test was not done.

Case 3 (Building Material Testing Center, Urawa Japan), 27 February 2013

Bar	No.	Section area (mm2)(diameter)	Yield stress (N/mm2)	Tensile stress (N/mm2)	Elongation %	Yong's modulus X 10^5N/mm2
Plain bar 10mm	1	82.0 (10.22)	316	464	26	--
	2	81.2 (10.17)	320	464	33	--

Structural Test by CNCRP

	3	82.2 (10.23)	346	478	30	2.02×10^5
	Ave.	81.8	**327**	469	29	--
Plain bar 6mm	1	36.1 (6.78)	Not clear	449	24	--
	2	35.5 (6.72)	Not clear	438	18	--
	3	41.4 (7.26)	561	632	--	1.95×10^5
	Ave.	37.7	----	506	(21)	--
Deformed bar 10mm	1	79.0	(391)	569	--	--
	2	79.0	(392)	526	24	--
	3	79.0	379 (0.2%)	542	21	1.89×10^5
	Ave.	79.0 (nominal)	**(387)**	546	(22)	--

Note;

1) Young's modulus was measured by providing strain gauge for No. 3 of each type.

2) Plain bar 6mm, clear yield stress of No.1 and No.2 of plain bar 6mm was not observed.

Yield stress of No.3 was bigger than tensile stress of No.1 and no.2, and material grade seems different from that of No.1 and No. 2.

It is supposed that yield stress will be 0.65 times 444 (ave. tensile stress of No.1 and No.2) is 289 N/mm2

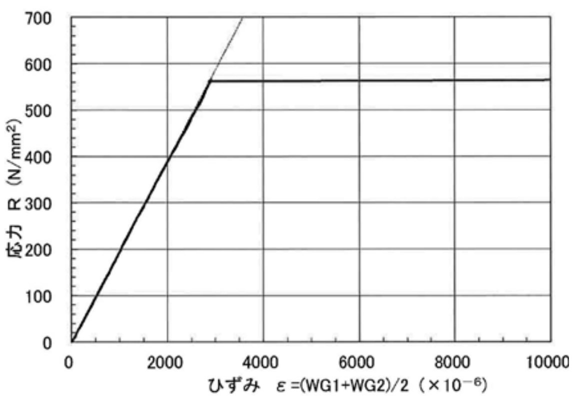
3) Deformed bar 10mnm; Lot of No. 1 and No.2, No.3 might be different, because shape of rib is different.

4) Deformed bar 10mm; Clear yield stress was not observed and stress of 0.2% strain was used for No.3. Yield stress of No.1 and No.2 are also shown with parenthesis as reference information.

5) Elongation is shown, but the specimen that the fracture occurred at outside of the measurement points is not shown.

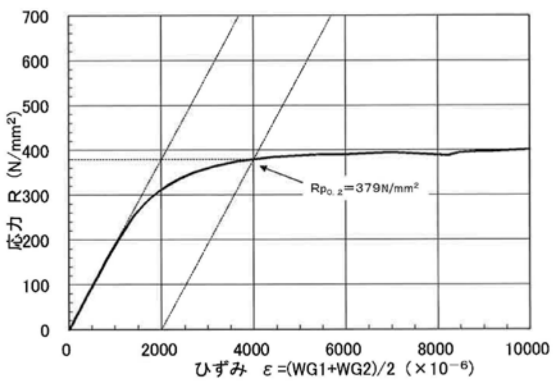
Stress-strain curve, Urawa building material lab. in Japan

φ6mm



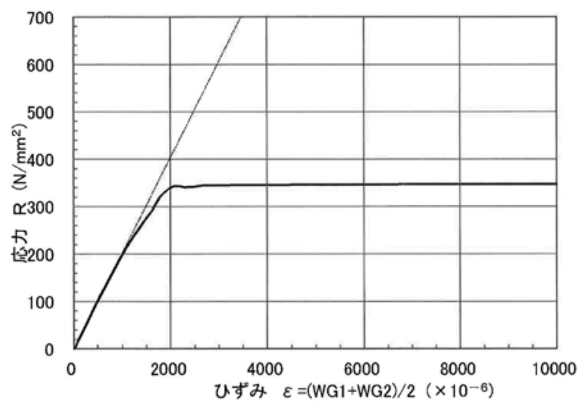
図ー1　応力ーひずみ曲線（φ6mm）

D10mm



図ー3　応力ーひずみ曲線（D10）

φ



2) Re-bar tensile test in Japan and Bangladesh for Japanese made re-bar 2013/05/15

1: Building material testing center, **Urawa branch, Japan** 浦和建材試験所

Date: 18 January 2013

Contents:

Re-bar: SD295A, diameter 10mm, nominal area A= 71.33mm2, weight w=0.560kg/m

Modulus of elasticity was measured through provided strain gauges.

Result:

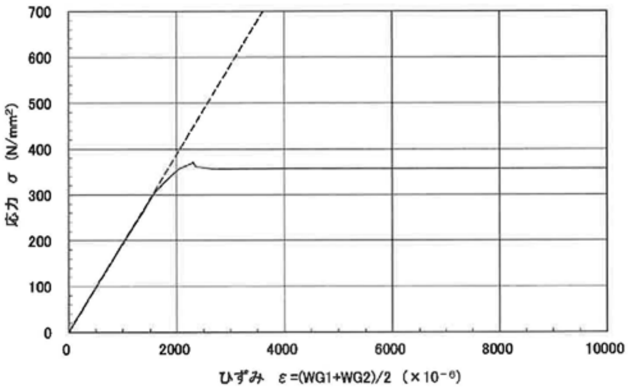
	Yong's modulus (N/mm2)	Yield load (kN)	Yield stress (N/mm2)	Tensile load (kN)	Tensile stress (N/mm2)	Elongation (%)
No. 1	----	27.6	387	36.4	510	29
No. 2	----	26.8	376	36.2	508	29
No. 3	1.94×10^5	26.7	374	36.4	510	27
Average	----(100%)	27.0(100%)	379	36.3(100%)	509	28(100%)

1) 1,000kN capacity automatic universal testing machine (Maekawa manufacturing). Maintenance of a machine is done annually by the maker. 1st class level is maintained.

2) Data-logger is used for elastic modulus to get data from strain gauges on re-bar.

3) Elongation is measured by a Nogisu.

Stress-strain curve is as follow;



図ー1 応力ーひずみ曲線

2.BUET, Date; 24 Jan 2013. It is noted that there are 5 universal machines at the lab.

	Yong's modulus (N/mm2)	Yield load (kN)	Yield stress (N/mm2)	Ultimate load (kN)	Ultimate stress (N/mm2)	Elongation (%)
No. 1	1.98×10^5	26.0	330	36.0	450	32
No. 2	1.98×10^5	26.7	340	36.0	450	34
No. 3	2.02×10^5	26.3	335	35.0	450	32
Average	1.99×10^5 (103%)	26.3(97%)	335	35.7(98%)	450	33(118%)

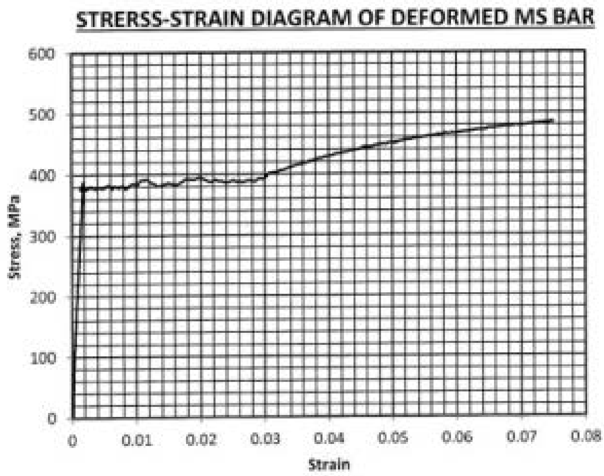
Actual diameter, 9.35mm is shown. Strain is measured based on 200mm gauge length.

Unit weight; 0.539kg/m (96%of the measurement in Japan)

Section area; 78.9mm2 (No.1), 78.5mm2 (No.2), 78.5mm2 (No.3), are calculated from yield load and yield stress. Nominal area of 79mm2 is shown in the test report. 71.33m2 is the nominal area of SD295A.

Load is compared with others, and not stress, since used section area was different.

Stress-strain curve by BUET is shown;



3. UAP, Date; 30 Jan 2013

	Yong's modulus (N/mm2)	Yield load (kN)	Yield stress (N/mm2)	Ultimate load (kN)	Ultimate stress (N/mm2)	Elongation (%)
No. 1	--	19	271	33	462	25
No. 2	--	19	271	31	434	24
No. 3	--	23	325	34	475	24
Average	--.	20(75%)	289	33(90%)	457	24(86%)

Measured actual diameter 9.50mm is shown.

Stress-strain test was not executed, because equipment is under repair.

4. HBRI (Housing and Building Research Institute), Date; 18 April 2013. Stress is compared.

	Yong's modulus (N/mm2)	Yield load (kN)	Yield stress (N/mm2)	Ultimate load (kN)	Ultimate stress (N/mm2)	Elongation (%)
No. 1	--	28.9	368.	37.8	482	21.9
No. 2	--	29.4	374	38.1	485	22.5
No. 3	--	27.9	355	38.0	484	19.5
Average	--.	28.7(106%)	365	38.0(105%)	483	21.3(76%)

Stress was converted to load using section area of 78.5mm2 (10mmRB) shown in the test report. A=71.3mm2 (D10) .

3.5 Consideration

1) Evaluation of maximum strength

(1) Comparison of experimental result and analysis (unit; ton)

Observed maximum load for positive and negative loading are compared with the calculated strength as shown.

	Experimental load, Qe (ton)			Analytical strength at collapse mechanism, Qa (ton)			
Specimen no. (date)	Positive loading	Negative loading	Average	Calculated strength, Qa	Qe(posi.) /Qa	Qe(nega.) /Qa	Note
1 (11/5,6)	4.62	4.70	4.66	5.22 (5.16)	0.89 (0.89)	0.91 (0.91)	Strong beam (in case Fc14.9)
2 (11/10,11, 12)	4.83	4.57	4.70	5.77	0.84	0.79	Strong beam
3 (11/27,28)	7.34	6.97	7.16	3.42(shear) +2.93=6.35	1.15	1.09	Strong beam with brick wall
4 (12/4)	6.84	6.94	6.89	(6.35)	(1.08)	(1.09)	Supposed same to No.3
5 (11/18,19, 20)	6.35	5.17	5.76	4.42 (4.63)	1.44 (1.37)	1.17 (1.12)	Standard beam (in case Fc18.5)
6 (11/14,15)	4.28	5.12	4.70	4.42	0.97	1.16	Standard beam
7 (11/24)	4.75	5.32	5.04	4.98	0.95	1.07	Deformed bar

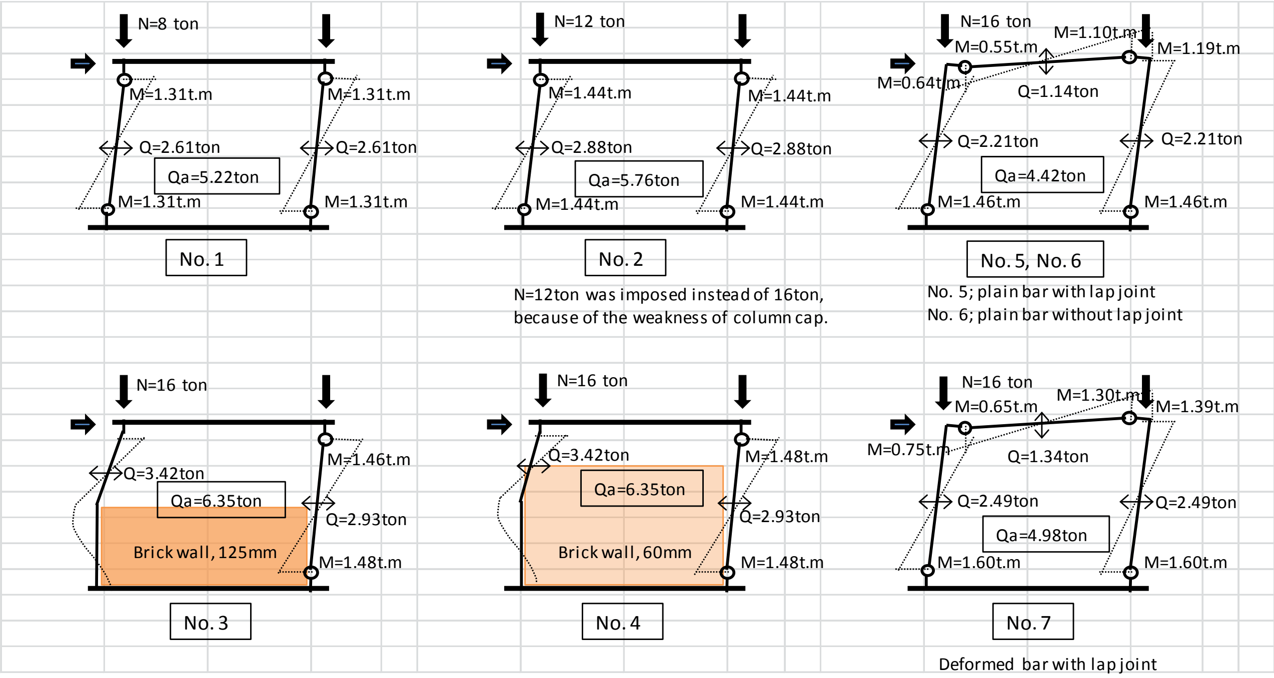
Conditions of strength calculation:

1. Strength at collapse mechanism is calculated using concrete strength of 16.5Mpa, and re-bar yield stress of, 327N/mm2 for plain bar 10mm,
 289 N/mm2 for plain bar 6mm, and
 387 N/mm2 for deformed bar 10mm
2. Provided axial load is 8 ton for No.1, 12 ton for No.2, and 16 ton for No. 3 to No. 7
3. Column collapse mechanism is supposed for columns of No.1 and No.2, which is strong beam type.
4. Column collapse mechanism is supposed for No.3 and No.4. Clear span of left column is supposed as 500mm and right column is 1,000mm. Shear strength is 3.42ton/column for left column of No. 3 is smaller than shear force at flexural strength 4.40 ton in case clear span length is 500mm. 3.42 (left column) plus 2.93 (right column) is 6.35 ton.
5. Column collapse at the bottom and beam collapse at the top of frame is supposed for specimen No. 5, No.6 and no.7.

(2) Supposed collapse mechanism and strength

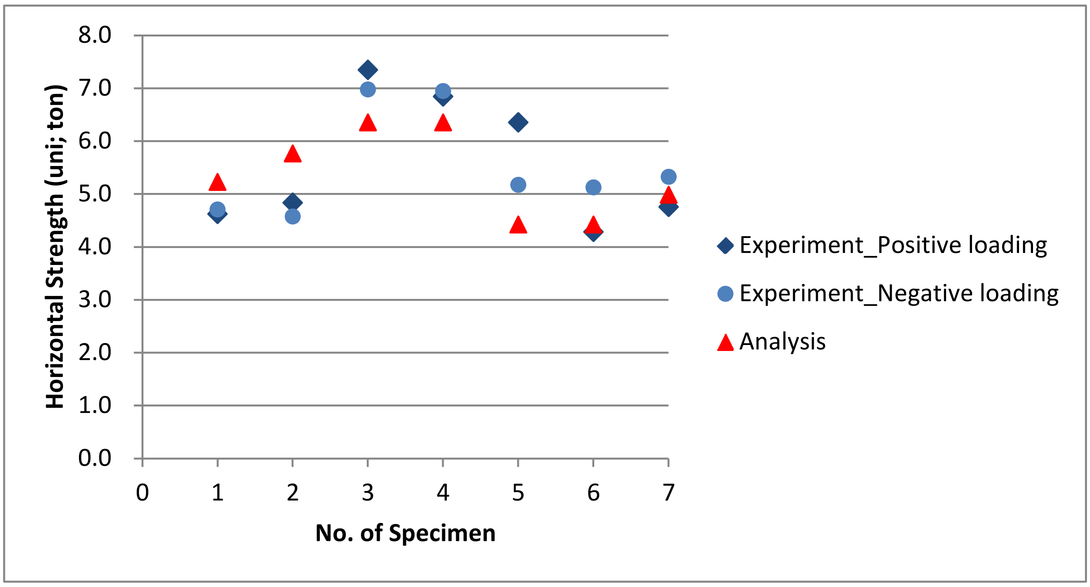
Supposed collapse mechanism, member and frame strength (Qa) of each specimen are shown below.

Structural Test by CNCRP

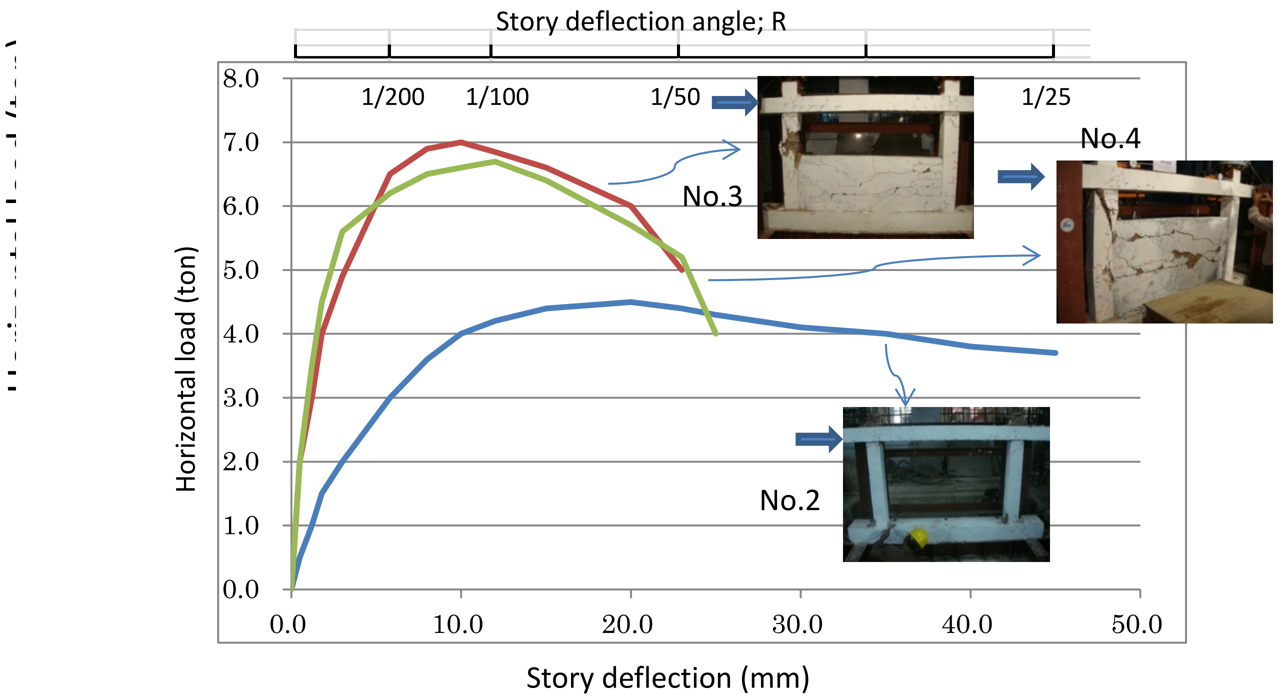


Note; 1ton=9.80kN, 1m=39.4in=3.28ft

Calculated strength is compared with experimental result.



Supposed simplified monotonic load-deflection curve for specimen No.2, No.3 and No.4



Appendix

Flexural strength (ref.1)

In the following formula, 0.7*at*σ*D was used instead of 0.8*at*σ*D, considering the small size of the specimen.

For $N_{max} \geq N > 0.4b \cdot D \cdot F_c$

$$M_u = \left\{0.8a_t \cdot \sigma_y \cdot D + 0.12b \cdot D^2 \cdot F_c\right\} \cdot \left(\frac{N_{max} - N}{N_{max} - 0.4b \cdot D \cdot F_c}\right)$$

For $0.4b \cdot D \cdot F_c \geq N > 0$ (N・mm)

$$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.5N \cdot D \cdot \left(1 - \frac{N}{b \cdot D \cdot F_c}\right)$$

For $0 > N \geq N_{min}$

$$M_u = 0.8a_t \cdot \sigma_y \cdot D + 0.4N \cdot D$$

(A1.1-1)

where:

N_{max} = Axial compressive strength $= b \cdot D \cdot F_c + a_g \cdot \sigma_y$ (N).

N_{min} = Axial tensile strength $= -a_g \cdot \sigma_y$ (N).

N = Axial force (N).

a_t = Total cross sectional area of tensile reinforcing bars (mm^2).

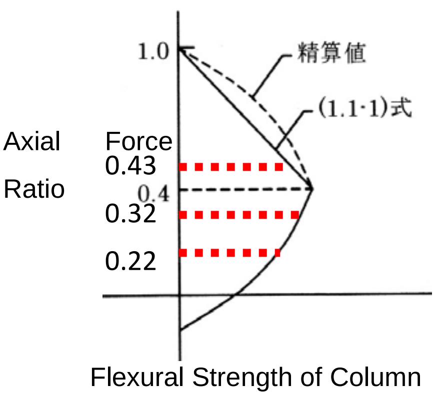
a_g = Total cross sectional area of reinforcing bars (mm^2).

b = Column width (mm).

D = Column depth (mm).

σ_y = Yield strength of reinforcing bars (N/mm^2).

F_c = Compressive strength of concrete (N/mm^2).



Shear strength of column (ref.1)

$$Q_{su} = \left\{ \frac{0.053 p_t^{0.23}(18+F_c)}{M/(Q \cdot d)+0.12} + 0.85\sqrt{p_w \cdot {}_s\sigma_{wy}} + 0.1\sigma_0 \right\} \cdot b \cdot j \qquad \text{(N)} \qquad \text{(A1.1-2)}$$

where:

p_t = Tensile reinforcement ratio (%).

p_w = Shear reinforcement ratio, p_w =0.012 for $p_w \geq 0.012$.

${}_s\sigma_{wy}$ = Yield strength of shear reinforcing bars (N/mm^2).

σ_0 = Axial stress in column (N/mm^2).

d = Effective depth of column. D-50mm may be applied.

$\frac{M}{Q}$ = Shear span length. Default value is $\frac{h_0}{2}$.

h_0 = Clear height of the column.

j = Distance between centroids of tension and compression forces, default value is 0.8D.

(b) If the value of $M/(Q \cdot d)$ is less than unity or greater than 3, the value of $M/(Q \cdot d)$ shall be unity or 3 respectively in using Eq. (A1.1-2). And if the value of σ_0 is greater than 8N/mm^2, the value of σ_0 shall be 8N/mm^2 in using Eq. (A1.1-2).