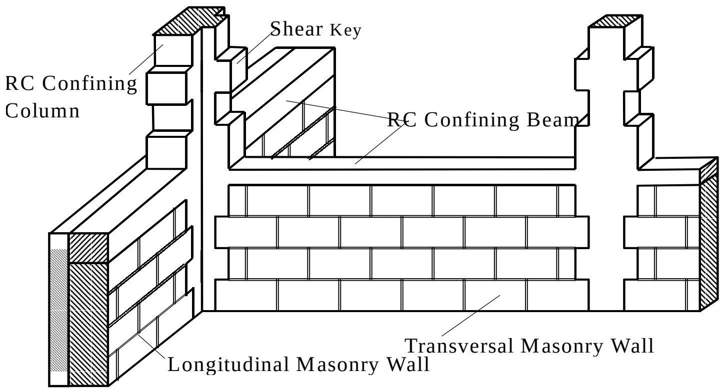
EXPERIMENTAL AND ANALYTICAL STUDIES ON SEISMIC RESISTING BEHAVIORS OF COMPOSITE BLOCK MASONRY WALL

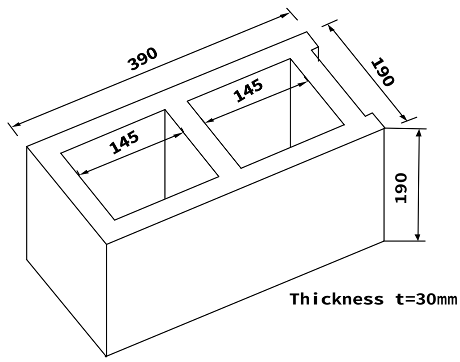
Purushotam DANGOL*[1], Norio HORI*[2], Tetsuya NISHIDA*[3], Norio INOUE*[4]

ABSTRACT: Based on experiments, strength and deformation behaviors of composite block masonry wall having reinforced concrete beam and column with shear keys were studied. A numerical analysis is performed by Rigid Body Spring Model to simulate experimental results. This method is very suited towards the analysis of structures composed by discontinuing material properties like masonry wall. The model consists of finite number of small rigid bodies connected with normal and shear springs on the boundaries of two neighboring rigid bodies.
KEYWORDS: Composite block masonry wall, shear keys, rigid body spring model, joint mortar, seismic resistant, RC confining beam and column

1. INTRODUCTION

The highly earthquake occurring area like South Asia, Middle and South America and other developing countries has not so many buildings designed for withstanding severe earthquake load. Generally in these countries buildings have been constructed by using very economical construction materials like clay bricks and concrete hollow blocks. Composite block masonry wall consists of block masonry wall surrounded by reinforced concrete beams and columns with shear keys. Reinforced concrete column and beam are constructed to delay the breaking duration of the cracked block masonry and to improve the ductility of wall. Shear keys are constructed on the columns for controlling slip and making good bond with concrete block. **Fig.1** shows the detail of composite block masonry wall. In this study, composite block masonry wall was tested with cyclic horizontal load under constant normal stress 0.5 MPa to investigate its earthquake resisting behaviors and to simulate its experimental results. Rigid Body Spring Model (hereafter RBSM) was used for simulating results obtained from the performed experiment.





Concrete Block

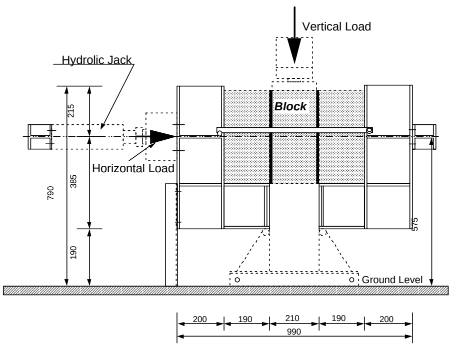
Fig.1 Composite block masonry wall

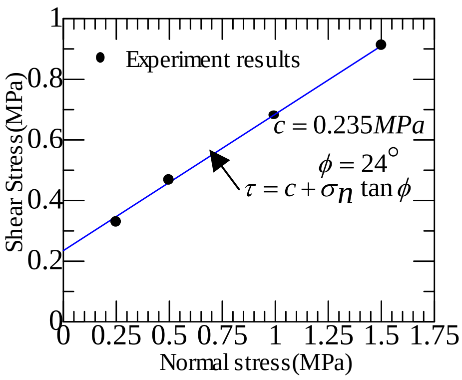
*1. Dept. of Architecture and Building Science, Tohoku University , Member of JCI
*2. Dept. of Architecture and Building Science, Tohoku University, Dr.Eng., Member of JCI
*3. Dept. of Arch. and Environment System, Akita Prefectural Univ., M.Eng., Member of JCI
*4. Dept. of Architecture and Building Science, Tohoku University, Dr.Eng., Member of JCI

2. EXPERIMENTAL PROCEDURES

2.1 BLOCK MASONRY ELEMENT AND ITS EXPERIMENT

Fig.2 shows test set up and specimen of block masonry made of three blocks with cement lime mortar in proportion of cement:lime:sand equal to1:0.65:6.59 ratio having compressive strength 9MPa. Specimens were loaded vertically under the constant normal stress of 0.25MPa, 0.5MPa, 1.0MPa, 1.5MPa respectively. The purpose of experiment is to investigate cohesion and the internal frictional angle of joint mortar. Normal and shear stress shown in **Fig.3** are calculated by appearance area $(390mm \times 190mm)$ neglecting holes. The compressive strength 4.80MPa and modulus of elasticity 5.40GPa were investigated by compression test as shown in **Fig.4**.





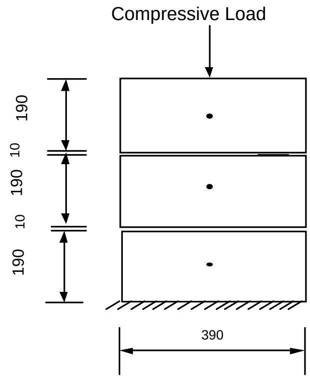


Fig.2 Shear Test **Fig.3 Results of joint mortar** **Fig.4 Compression Test**

2.2 COMPOSITE BLOCK MASONRY SPECIMEN

Fig.5 shows composite block masonry wall specimen. The specimen was half scaled of single story and single span but the actual sized blocks were used (thickness two times). The upper parts over beam were used to distribute axial load uniformly over wall. The reinforcements SR235 were used in specimen. Strength, cohesion, angle of internal friction and elastic modulus of concrete and three layered block masonry (area neglecting holes) were 30.5 MPa, 4.20 MPa , 37° , 24.5 GPa (design parameters) and 4.80MPa, 0.235MPa, 24°, 5.40 GPa (from the experimental results) respectively.

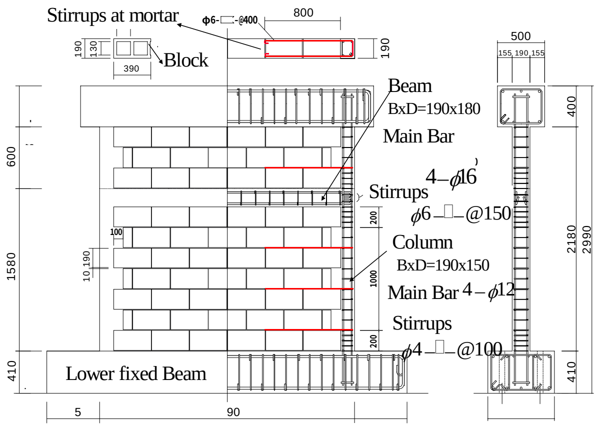


Fig.5 Test specimen

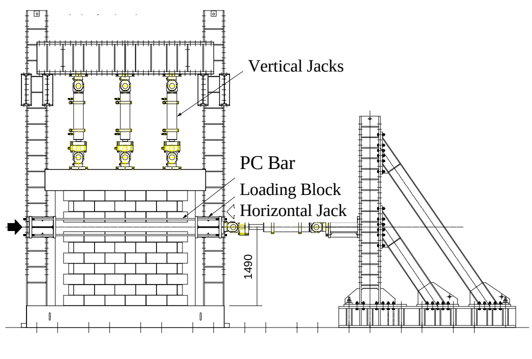


Fig.6 Loading Apparatus

Reinforcements were not inserted into the block masonry wall in vertical direction but inserted in horizontal direction up to 800mm length from the columns on alternate layer. The sequences of construction of specimen are (1) fastening of reinforcement (2) constructing block masonry wall (3) fastening of beam reinforcement 4) casting concrete on RC columns and beam.

As considering vertical stress 0.1 MPa per one story, experiment was conducted under 0.5 MPa for 5 stories building. **Fig.6** shows loading apparatus. It consists of 3 vertical jacks for applying the axial loads and horizontal jack for shear force and transducers were used to measure relative displacement of various points on wall.

3.CONSIDERATION OF EXPERIMENTAL RESULTS

3.1 FAILURE MODE

Fig.7 shows crack patterns of block masonry wall obtained from the performed experiment. It was seen that the initial tensile cracks on the column of the tension side of wall were developed when deformation angles reached 1/5000 and on block masonry wall when deformation angle reached 1/1500 respectively. Stepwise cracks were started to develop further from the column of tension side towards the block masonry wall after reaching the deformation angle approximately 1/1000.Without further increasing the loads, width of cracks and slip were increased. The inclined cracks on the column of the compression sides of wall and block elements began to develop when the deformation angle was approximately 1/250 and 1/500 respectively. Column on the compression side of wall almost collapsed on the deformation angle approximately 1/167.The main reinforcements on columns were not yielded.

3.2 LOAD-DISPLACEMENT RELATION

Load displacement relation of the center of upper beam is depicted in **Fig.8**. It was seen that the wall was in the elastic limit up to deformation angle 1/3000. Deformation flow was occurred after reaching horizontally applied load 330 kN. After this load cycle, furthermore, deformation angle increased up to 1/500 when the maximum load applied to the specimen. The maximum resisting force of composite block masonry wall is equal to 370.2 kN. Load was decreasing gradually after attaining loading cycle 1/250 and 1/167. It is showed that cyclic loop of energy consumption was larger than general reinforced concrete wall.

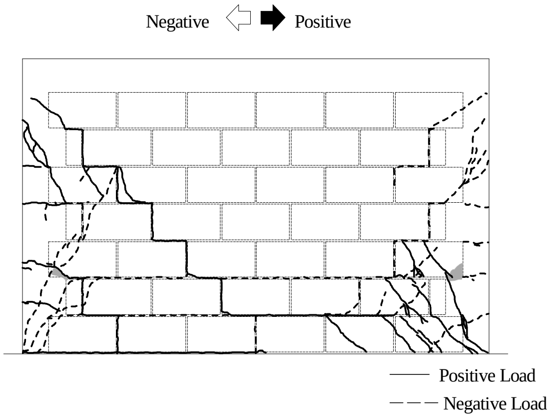


Fig.7 Crack patterns

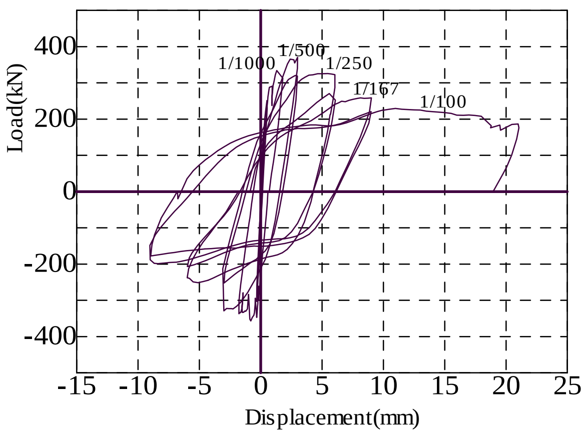


Fig.8 Load displacement relation

3.3 CONSIDERATION OF THE RESISTING FORCE MECHANISM

The resisting force mechanism of the composite block masonry wall is depicted in **Fig.9**. In case of the maximum resisting force obtained considering before cracks on the block masonry wall, column on the tension side of wall acted as 'TIE' and the diagonal block masonry wall as 'STRUT'. As the stepwise cracks appeared on the block masonry wall, load could not be increased but developed slip on the boundaries of mortar joints and block due to the inclined compressive stress of strut and the frictional force between mortar joints and block. Cyclic loop of loading was large due to the residual slip deformation remained on the joint mortar.

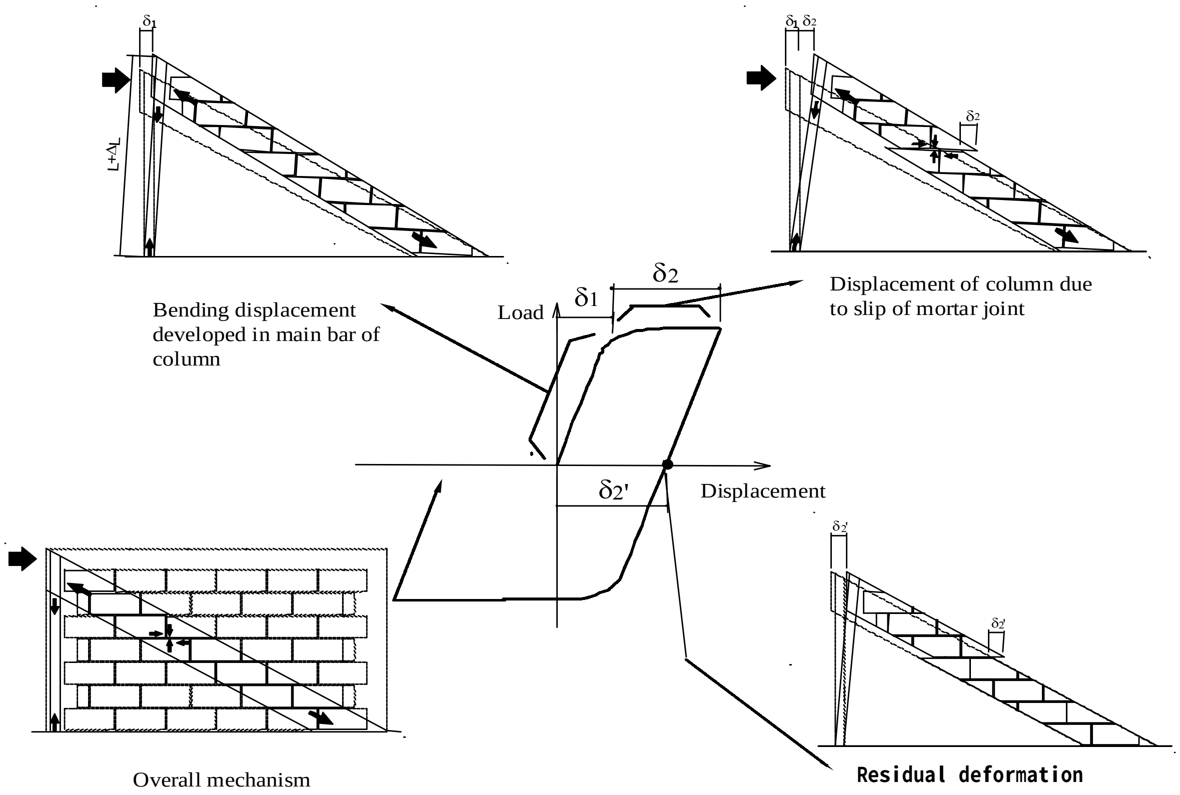


Fig.9 Resisting force mechanism

4. SIMULATION ANALYSIS BY RIGID BODY SPRING MODEL

4.1 CONCEPT OF RIGID BODY SPRING MODEL

The model as shown in **Fig.10** consists of rigid bodies connected with normal and shear spring distributed on the boundaries of two neighboring rigid bodies. Three degree of freedoms are defined at the center of rigid body as the nodal displacement: two transitional and one rotational degree of freedom [1]. The relative displacements of springs on the boundaries of rigid bodies were defined considering $[B]$and δ_n, δ_sdisplacement of center of rigid bodies as in Eq.1.

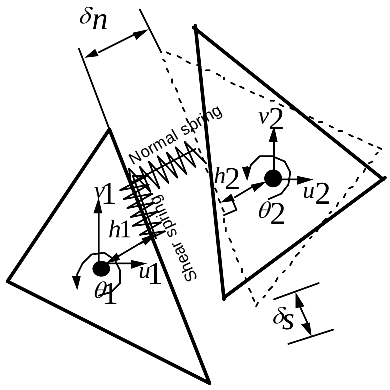


Fig.10 Rigid body spring Model

$$\begin{Bmatrix} \delta_n(x,y) \\ \delta_s(x,y) \end{Bmatrix} = [B(x,y)]\{u_1, v_1, \theta_1, u_2, v_2, \theta_2\}^t \quad \text{.........(1)}$$

Then, stress and relative displacement relation of springs is given by Eq.2

$$\begin{Bmatrix} \sigma_n(x,y) \\ \tau_s(x,y) \end{Bmatrix} = [D] \begin{Bmatrix} \delta_n(x,y) \\ \delta_s(x,y) \end{Bmatrix} \quad \text{.................. (2)}$$

where,

$$[D] = \begin{bmatrix} k_n & 0 \\ 0 & k_s \end{bmatrix}, k_n = \frac{E}{(1-\upsilon^2)(h_1+h_2)}, k_s = \frac{E}{(1+\upsilon)(h_1+h_2)}$$

k_n, k_s - Stiffness of normal and shear spring, E- Tangential modulus of elasticity, υ - Poisson's ratio and h_1, h_2 – Perpendicular distance between boundary and center of rigid body.
Element stiffness of springs [1] on the boundary is given as

$$[K] = t\int_s [B]^t [D][B] ds \quad \text{..(3)}$$

Where ,

t- Thickness of element boundary, s- Variable length of element boundary

4.2 NORMAL STRESS-STRAIN RELATION

Normal stress-strain relation was decided by the model shown in **Fig.11**. It is assumed that tensile strength of structure is 1/10 of the compressive strength σ_B. Crushing is occurred after tensile strain attained 20 times of tensile yield strain. The stress at the first and second yielding level are $0.5\sigma_B$ and $0.95\sigma_B$ respectively. Tangential modulus of elasticity E_c is reduced to $0.5E_c$ after first yielding. Modified Newton-Raphson method is used to solve non-linearity [2] .

4.3 SHEAR STRESS-STRAIN RELATION

Using the flow rule on the slip surface due to shearing, the following yield function to define the constitutive equation for post yielding stage is assumed for RBSM models

Yield function $f = \tau_s^2 - (c - \sigma_n \tan\phi)^2$ ……………………………………………..(4)

where, c - Cohesion, ϕ - Angle of internal friction. Shear yield surface is assumed as shown in **Fig.12**. Shear slip occurs after exceeding shear yield strength given by Mohr-Coulomb's equation [2] and develops along Mohr-Coulomb's shear yield surface with changing constitutive matrix $[D]^p$ according to the flow rule of plasticity. The constitutive matrix after yield surface is as follow.

$$[D]^p = [D]^e - [S] \quad \text{...(5)}$$

where,

$$[S] = \frac{1}{F}\begin{bmatrix} ((c-\sigma_n \tan\phi)\tan\phi k_n)^2 & \tau_s(c-\sigma_n \tan\phi)\tan\phi k_s k_n \\ \tau_s(c-\sigma_n \tan\phi)\tan\phi k_s k_n & \tau_s^2 k_s^2 \end{bmatrix}, \qquad [D]^e = \begin{bmatrix} k_n & 0 \\ 0 & k_s \end{bmatrix},$$

$$F = \tau_s^2 k_s + \{(c - \sigma_n \tan\phi)\tan\phi\}^2 k_n$$

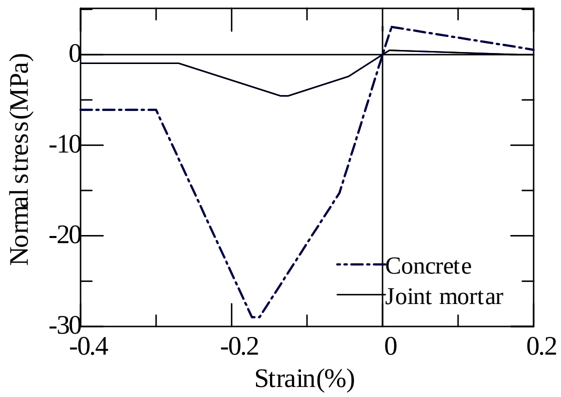


Fig.11 Normal stress strain relation

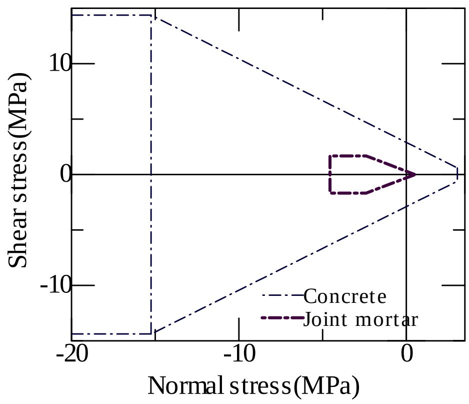


Fig.12 Shear and Normal stress relation

4.4 STRESS-STRAIN RELATION OF REINFORCEMENT

The stress-strain relation of reinforcement is assumed as bi-linear model [1]. The yielding of reinforcement occurs when the induced stress exceeds the yield strength. Reinforcement is assumed to be effective only in normal direction.

5. RBSM ANALYSIS MODEL OF SPECIMEN

Reinforced concrete elements were divided into the rectangular and triangular elements as rigid bodies considering the cracks and each block was also considered as one rigid body as shown in **Fig.14**. Axial loads were applied at center of rectangles of upper RC beam. The lower beam was assumed as fixed supports. Each side of rectangular, triangular elements and block was considered as boundary and its element stiffness was decided considering its material properties.

6. ANALYZED RESULTS AND COMPARISON WITH EXPERIMENTS

Load-displacement relation showed in **Fig.13** has good agreements between the analyzed results and experimental results. Displacement is increased rapidly after 2.2mm. Regarding the analysis, ultimate stages are occurred when joint mortars are slipped and concrete on the compression side columns are cracked. **Fig.14** shows the rotation, cracks of both side column and shear slippage of the joint mortar. **Fig.15** shows the resultant stress of normal and shear stress on each boundary of rigid body. It is understood that block wall is acted as strut and the inclined compressive forces are developed by compressive force of block and frictional force of the joint mortar.

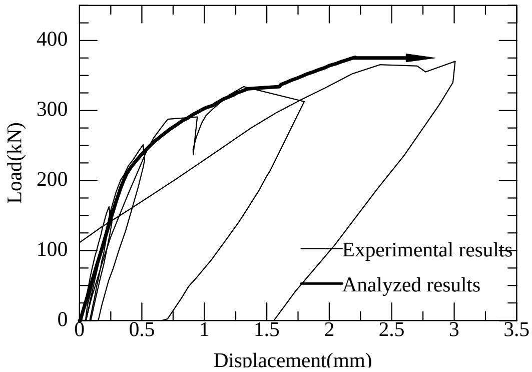


Fig.13 Load displacement relation

7.CONCLUSION

Experiment and RBSM analysis were performed to investigate strength, failure mode of composite block masonry wall and to develop tools for its structural analysis. Considering experimental and RBSM analysis results, this research came to conclusions that:

1) Maximum strength of composite block masonry under constant vertical stress is investigated.
2) The crack patterns as well as the resisting force mechanism of different elements that constructed composite block masonry wall are known.
3) The cyclic loop of energy consumption is larger than general reinforced concrete wall.
4) RBSM analysis is able to simulate overall behavior of load displacement relation. It is proved that RBSM analysis becomes a tool of the structural analysis of composite block masonry wall.

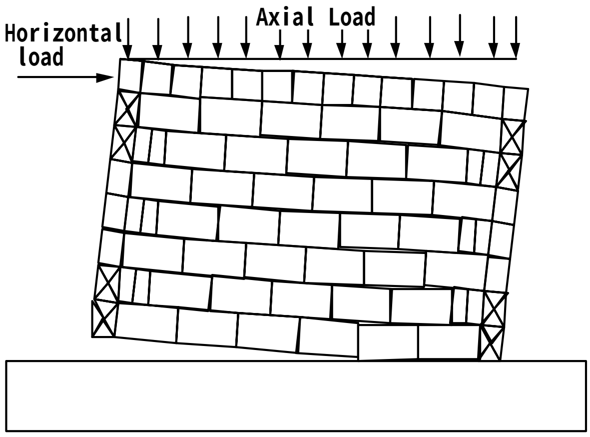


Fig.14 Failure mode at ultimate stage

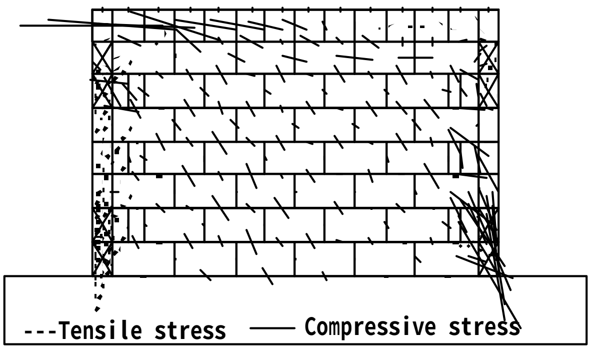


Fig.15 Stress distribution at ultimate stage

ACKNOWLEDGEMENT

Authors give sincere thank to Prof.Kobayashi, Dr.Teramoto of Akita Prefecture University, Mr. Hosi and Mr. Kimura of Tohoku university for their greatest helps to successfully complete the experiments related to this research work.

REFERENCE

1.Ueda, M. and Kawai T. " Evaluation of a Discrete Limit Analysis to the Reinforced Concrete Shear Walls,'' Japan Concrete Institute Seminar on Finite Element Analysis of Reinforce Concrete Structures, Vol.2, Tokyo, May 20-24 1985, pp.287-295.

2.Chen, W.F. "Plasticity in Reinforced concrete'', McGraw-Hill Book Company, New York,1982