

Experimental study of new seismic strengthening method for existing RC structure

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ABSTRACT: This report discusses the seismic strengthening method of existing reinforced concrete (R.C.) structure with H-shaped steel elements. By means of the installed steel frame, larger window opening can be set up at the center of strengthened steel frame. In this study, steel frame adopts strong axis of H-shaped steel elements. In addition to this, another steel frame with steel braces in the corners is also considered. Experimental results show that existing R.C. frames strengthened with H-shaped steel frame only, produces satisfactory aseismic effect. While, the R.C. frames strengthened with corner braces in addition to H-shaped steel frame, will preserve yielding strength and ductility excellently, under some special conditions. Through experimental and calculating works, it is verified that the ultimate shear strength of strengthened R.C. frame can be simply obtained by adding shear strength of the steel elements and existing R.C. frame on the basis of conventional calculating method.

1 INTRODUCTION

In recent years, from the observation of earthquake disasters, we can understand that the some existing R.C. structures are disqualified by aseismic design guide, so it is necessary to strengthen those existing R.C. structures. Up to now, there are some methods to strengthen the existing R.C. structures. One of these methods is to increase the number or the thickness of wall with reinforced concrete ¹⁾. Then, this method will result in increase of structural weight. Another method is to strengthen the existing R.C. structures by steel panel or braces with outer rims ²⁾ (shown in Fig.1). In this method, the existing R.C. structures and aseismic steel elements are connected in mortar joint with headed studs and resin anchors (shown in Fig.2). By this method, it avoids the increase of the weight of structure. So, it is useful when the capacity of foundation of the structure is uncertain. Moreover, it reduces time of erection, because the steel elements can be pre-fabricated in factory. This researches were developed in "Guideline for Repair and Strengthening Design of Existing Reinforced Concrete Buildings ³⁾".

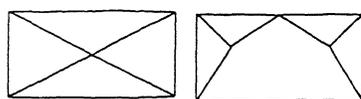


Figure 1. Strengthening methods with braces

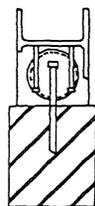


Figure 2. Typical detail of mortar joint

Now, we try to discuss the seismic strengthening method of existing R.C. structure with H-shaped steel elements. Steel frame adopts strong axis of H-shaped steel elements. In this study, two strengthening method are considered. By means of the installed steel frame, larger window opening can be set up at the center of strengthening portion, as result, the ventilate and lighting can be improved. In addition to this, the other steel frame with steel braces in the corners is also considered.

2 OUTLINE OF TEST

All specimens were performed on one-story, one-span, one-twice scale model. The dimension and bar arrangement of specimens were taken from the typical R.C. structure that need be strengthened in Kanagawa Prefecture. A series of five specimens was tested to verify validity and effectiveness of the strengthened existing R.C. structure. Two strengthening method are considered in this study. In the first method, R.C. structure is strengthen with H-shaped steel frame only (F-B, F-E). The second method, it is strengthened with corner brace besides H-shaped steel frame (F-A, F-D). Details of five specimens are illustrated as follow (shown in Fig.3- Fig.6): Specimen F-A is strengthened by the second method, as shown in Fig.3. Specimen F-B is strengthened by the first method that it is obtained by removing braces from specimen F-A. Specimen F-C is original R.C. portal frame. Specimen F-D is reformed from specimen F-A. Specimen F-D's panel (intersection of installed steel frame, tension brace and compression brace) is strengthened by welding 2-PL6-100x100 on front side and back side, as

shown in Fig.4. Specimen F-E is the same as specimen F-B, strengthened by the first method, but its web of steel frame is twice as thick as specimen F-B's. According to specimens F-D, F-E were tested after specimen F-A, F-B, F-C being tested, the average material properties (yield stress σ_y and ultimate stress σ_u) are summarized in Table 1, respectively. Concern-

ing to beam, cross-section shape of R.C. beam for specimens F-A, F-B, F-C are T-shaped. For the sake of easier fabricating, we take up beam of rectangular cross-section for specimens F-D, F-E. All of them have the same volume of reinforcement, as illustrated in Fig.5. The steel frame and original R.C. frame are jointed by using headed studs and resin anchors. Headed studs are welded to the out-side flange of steel frame, and headed resin anchors are driven into the R.C. frame. Then, they are all consolidated by no-shrinkage mortar and spiral. Detail of mortar joint is shown in Fig.6.

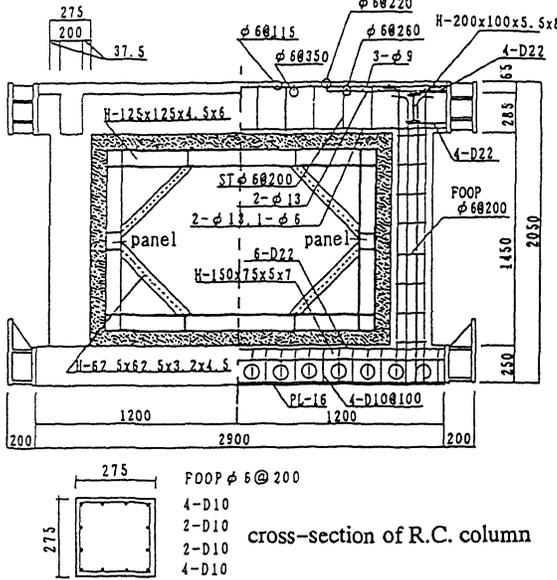


Figure 3. Configuration and dimension of specimen F-A

Table 1. Mechanical properties of materials

specimen	F-A, F-B, F-C		F-D, F-E	
	σ_y (MPa)	σ_u (MPa)	σ_y (MPa)	σ_u (MPa)
reinforcement bar				
D10 (column)	302	498	335	481
D10 (anchor)	351	541	345	470
$\phi 13$	349	416	343	423
$\phi 9$	235	410	—	—
$\phi 6$	262	515	343	423
stud $\phi 8$	221	329	319	490
H-shaped steel				
PL9	—	—	213	325
PL6	279	350	235	331
PL4.5	197	323	239	350
PL3.2	321	366	285	371
brace (H-shaped)	279	350	269	340
concrete		25		21
mortar		65		32

σ_y : yield stress σ_u : ultimate stress

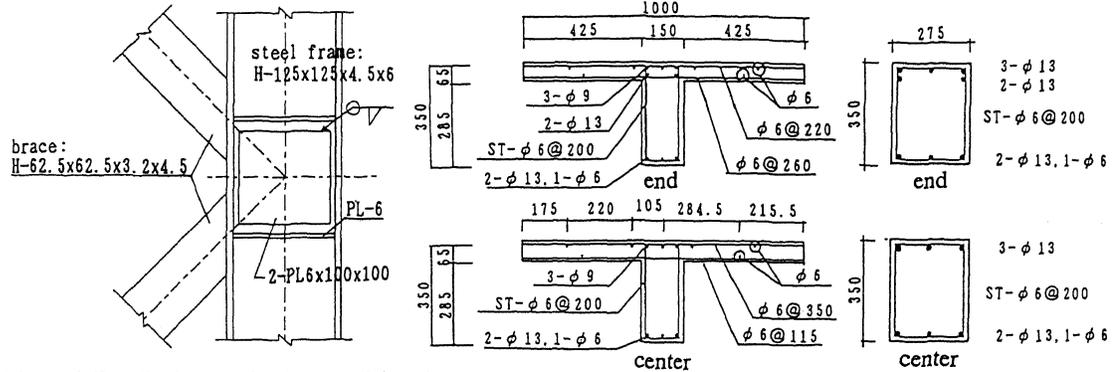


Figure 4. Detail of strengthening panel (F-D)

(a) F-A, F-B, F-C

(b) F-D, F-E

Figure 5. Cross-section of R.C. beam

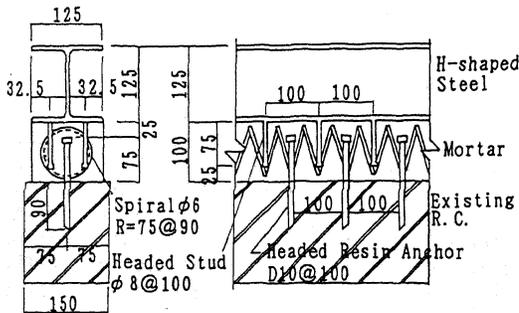


Figure 6. Detail of mortar joint

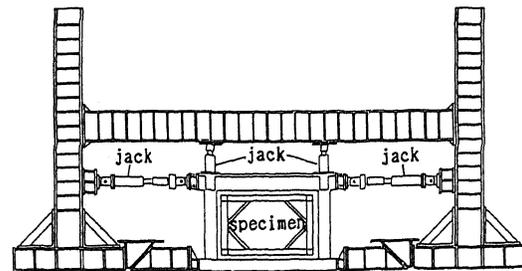


Figure 7. Loading scheme

3 METHOD OF TEST

Fig.7 shows the loading scheme. Top of each column was subjected to constant axial load of 294N, which corresponded to 3.94 MPa normal stress. Horizontal loads were applied at both ends of the girder by pulling and pushing to distribute the horizontal shear stress evenly over the entire wall section. Five cycles of horizontal loads were applied by deflection control. Measurement items included horizontal deflections, separation between steel frame and R.C. frame. Strains in main reinforcement and steel frame were also measured.

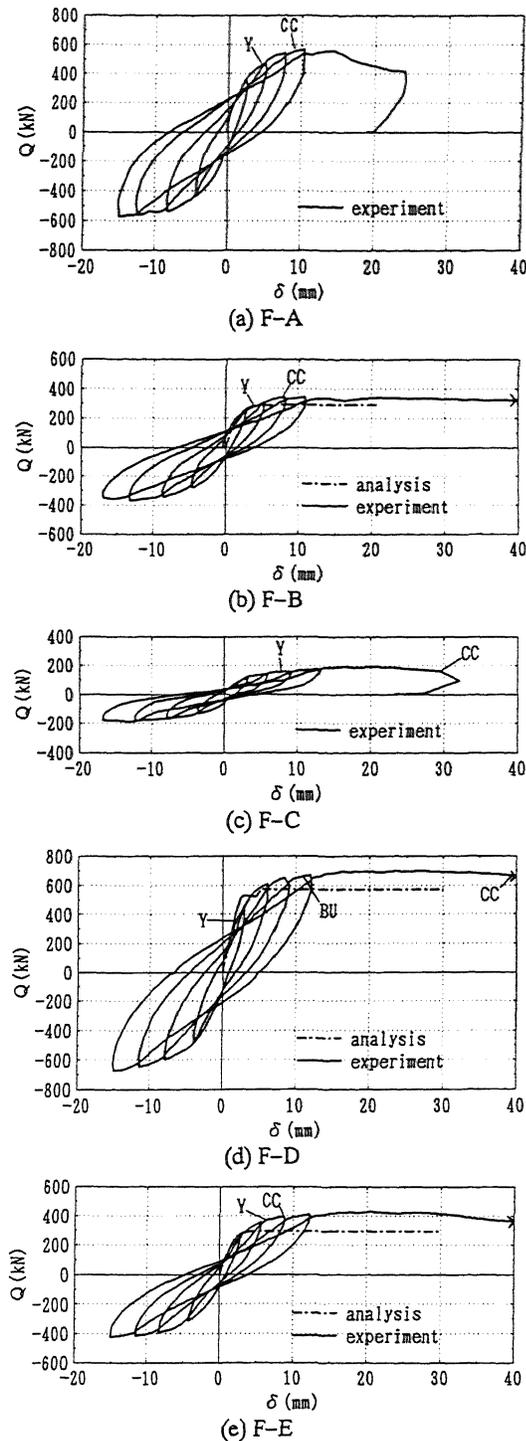
4 TEST RESULTS

Typical load-deflection relations are shown in Fig.8 with the point of occurrence of principal crack. Fig.9 shows final crack patterns of the specimens. The failure mode of all specimen was shear failure mode. All specimens' strengths were decreased after occurrence of shear failure of R.C. column. Fig.10 shows envelopes of load-deflection response of experimental results for specimens. Experimental results of the strengthened specimens are illustrated as follow.

From experimental results, strength of specimens F-B, F-E were nearly twice than non-strengthened specimen F-C's. From stable load-deflection relation as shown in Fig.10, they had a good ductility. The reason of this is that flexural shear crack was dispersed on the R.C. column. Web of specimen F-E's steel frame is twice as thick as F-B's, so the strength of specimen F-E was higher than that of specimen F-B. The shear yielding didn't occur at steel frame in the specimen F-E. Fig.11 shows the strain distribution of specimens F-B, F-E at the first cycle loading. From this figure, the phenomenon of slip occurred apparently, but the separation between R.C. column and steel frame didn't observe except corner from specimens F-B, F-E.

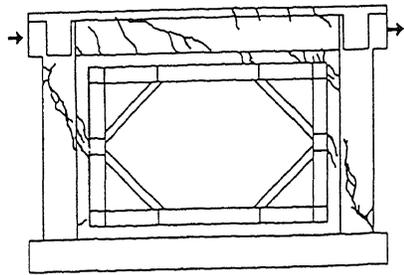
Strength of specimen F-A, F-D were nearly three times than specimen F-C's. In the case of specimen F-A, because of shear deformation of panel, a shear strength was applied at the midpoint of R.C. column. This resulted in a shearing failure characterized by the separation of the upper and low region of R.C. frame as shown in Fig.9(a) and in Photo.1. From this fact, the specimen F-A present low ductility. On the other hand, because the panel of the specimen F-D was strengthened by welding steel plate, this kind of shearing failure didn't occur. From the Fig.10, we can conclude that specimen F-D had a good ductility, and it was more resistant than specimen F-A.

Experiment results show that existing R.C. frames strengthened with H-shaped steel frame only, produces satisfactory aseismic effect. While, the existing R.C. frames strengthened with corner braces in addition to H-shaped steel frame, when panel was strengthened, and under the other condition (this will be described in the following), will preserve yielding strength and ductility excellently.

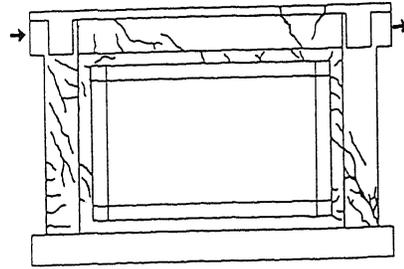


Y: yielding of main reinforcement in R.C. column
 CC: occurrence of shear crack in R.C. column
 BU: buckling of brace

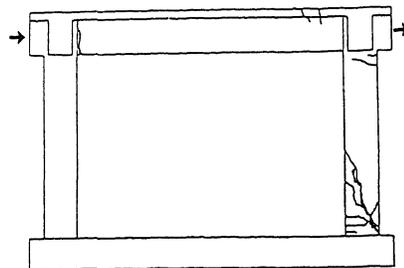
Figure 8. Horizontal load - deflection relationships



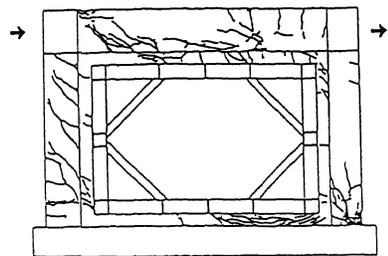
(a) F-A



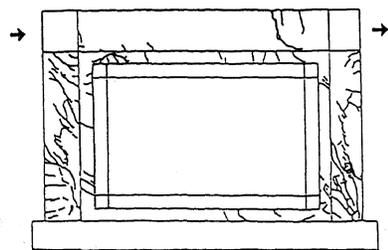
(b) F-B



(c) F-C



(d) F-D



(e) F-E

Figure 9. Crack patterns of specimens under positive loading

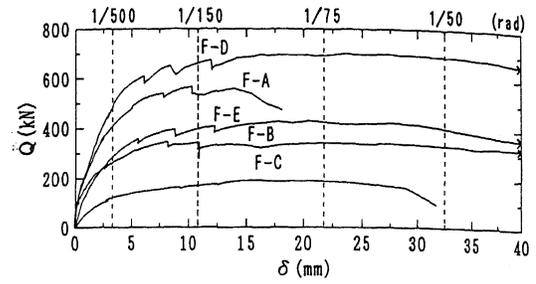
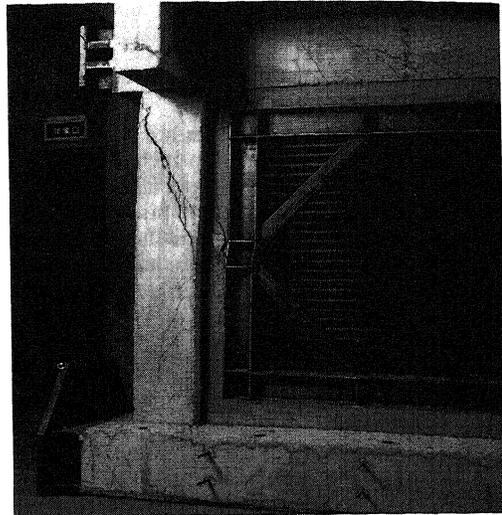
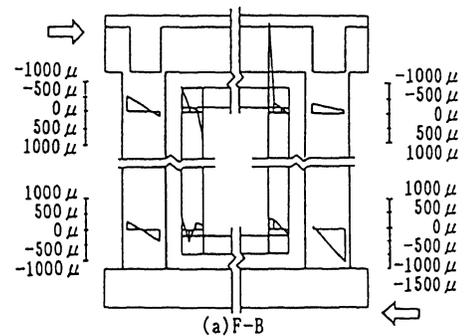


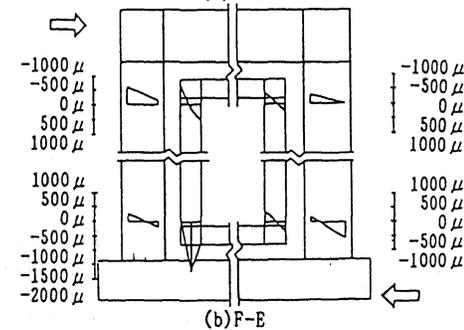
Figure 10. Envelopes of load - deflection relationships



Photograph 1. Specimen F-A



(a) F-B



(b) F-E

Figure 11. Strain distribution

5 ANALYSIS

On the basis of the results of tests on frames, we proposed an analysis using following the assumptions (shown in Fig.12 and Fig.13):

1. Beam is assumed as a rigid body.

2. Properties of materials (steel, reinforcement, concrete, mortar) are based on the test results of materials. Steel and reinforcement are assumed as perfect-elastoplastic property, and reinforcement is assumed to be not able to bear compressive stress. Concrete and mortar are assumed as tri-linear stress-strain relationship property, and they are assumed to be not able to bear tensile stress (shown in Fig.12). Moreover, Young's modulus ratio of concrete and mortar against steel is assumed as 10.

3. Flexural analysis is carried out on the composite column that is consisted of steel frame, R.C. column and mortar joint. It is assumed that curvature of steel element, R.C. column and mortar is the same.

4. Composite column is divided into 15 segments in the axial direction (shown in Fig.13)

5. The intersecting place of mortar and steel frame is assumed as complete slip, but no separation.

On the basis of the above assumptions, we can get Moment-Curvature relationship at each divided section, and obtain End Moment-End rotation relationship from integrating curvature distribution. The results of analysis are shown in Fig.8(b),(e). Analytic results agreed well with the experimental ones.

Specimen F-D is reformed from specimen F-A. In the specimen F-A, the shear deformation of panel caused by the braces, as shown in Photo.1. So, its strength decreased before the occurrence of tensile yielding or buckling of brace. From above reason, the panel of specimen F-D was strengthened sufficiently. So, it can avoid the same failure mode with specimen F-A's, and we can estimate strength of specimen F-D. Concerning to brace, to avoid failure of pull-out at mortar joint caused by tensile brace, it is necessary to let brace's tensile yielding occur before mortar joint fails. So, preliminary experiment was performed on beam of R.C.-Mortar-Steel as shown in Fig.14, to decide the dimension of brace. Pulling out load-deflection relation of test was given in this figure. Fig.15 shows the relationship of horizontal load and strain in the axial direction of brace, and indicates that compression brace's strain is higher than tension brace's one. In other words, tension brace is less efficacious than compression brace. From this fact, the frame can be modelled by setting a spring between mortar joint and tension braces' end as shown in Fig.16. Fig.17 shows the relationship of axial forces and displacement of braces' length when the mortar joint of tension brace's end is assumed as a spring (shown in Fig.16). This figure also indicates that under the same displacement, axial force of compression brace is larger than tension brace's before buckling of compression brace. Braces are disposed at the corners of steel frame, so a compression brace and a tension brace are attached on column. From illustrated above, axial forces of the tension brace and the compression brace are different. So, the absolute value of difference

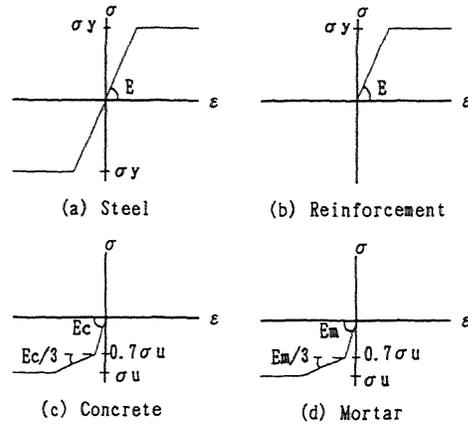


Figure 12. Stress - strain relationships

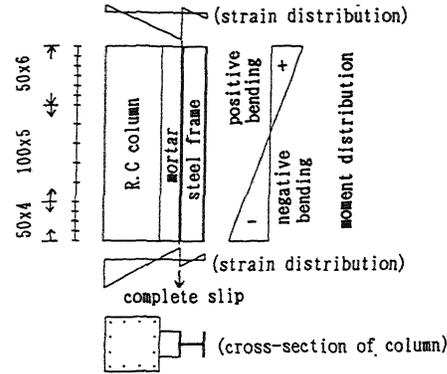


Figure 13. Division of columns in analysis

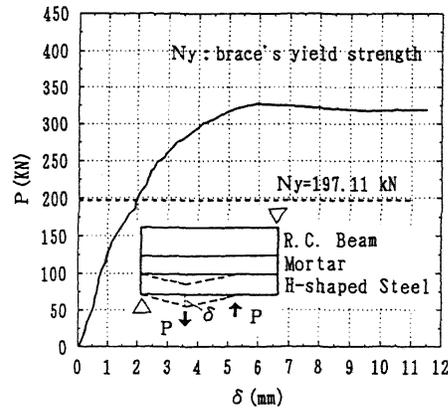


Figure 14. Pullout Loading - deflection relationships

between the horizontal component of axial force of the braces will act as shear stress on the column in the region attached by brace that have smaller axial force (shown in Fig.18). For specimen F-D, since braces are disposed at corners of steel frame, its effective buckling length is getting shorter, and reduction of strength is

small after buckling. Now, the coefficient of effective slenderness ratio is assumed as 0.7 for calculating the buckling strength of brace. So, it is considered that the influence of difference between axial force of tension brace and compression brace is small. From this fact, if column does not collapse under additional shear stress since braces, the brace with larger axial force will resist the horizontal load.

From above reasons, we use this model (shown in Fig.16 and Fig.18) to calculate braces' strength of specimen F-D. Assumptions of analysis are as same as mentioned above (F-B, F-E). Analytic result of specimen F-D can be obtained by adding shear strength of braces and frame (shown in Fig.8(d)). From Fig.8(d), the result of this analysis agreed well with the experimental one.

From above fact, it was verified that the ultimate shear strength of seismic strengthened R.C. frame can be approximately that obtained by adding shear strength of the steel elements and existing R.C. frame on the basis of conventional calculating method.

6 CONCLUSION

The following conclusions are made from this study

1. The R.C. structures can be strengthened by steel frame that adopts strong axis of H-shaped steel elements.
2. While the R.C. frame is strengthened by corner braces in addition to H-shaped steel frame, the structure will preserve excellently yielding strength. Though, its working must be under some conditions that shear deformation of the panel and the failure of pull-out in mortar does not occur.
3. The falling down of resistance of the frame will not occur when the brace buckles.
4. Through experimental and calculating works, it is verified that the ultimate shear strength of seismic strengthened R.C. frame can be simply obtained by adding shear strength of the steel elements and existing R.C. frame on the basis of conventional calculating procedure.

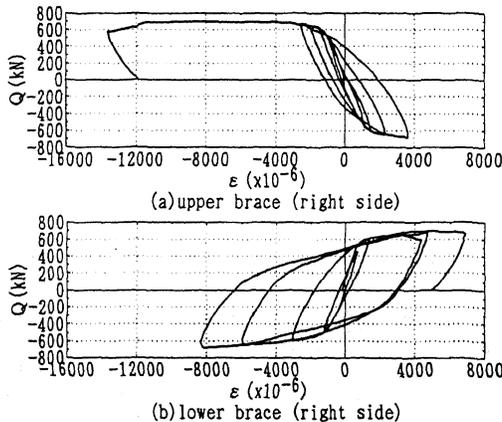


Figure 15. Horizontal load - strain of braces relationships

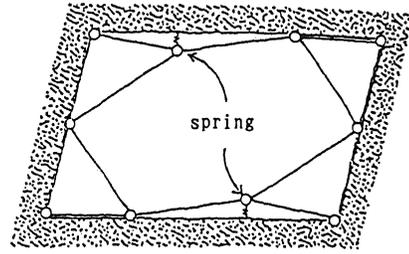


Figure 16. Model for calculating

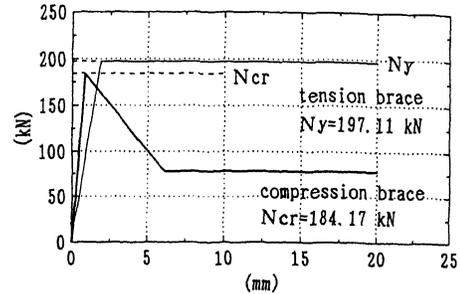


Figure 17. Load - displacement relationship of braces

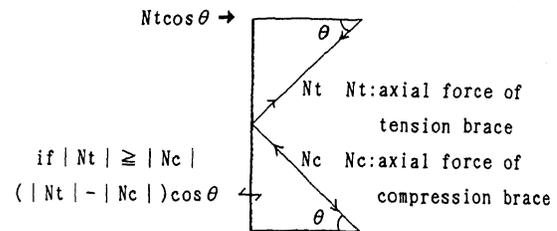


Figure 18. Horizontal load vs braces' axial forces

ACKNOWLEDGMENT

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