0585

ARRANGEMENT OF REINFORCEMENTS TO RAISE SHEAR RESISTANCE AND MAINTAIN THE DUCTILITY OF REINFORCED CONCRETE PIERS ON BRIDGES

Y SHIOI[1], A HASEGAWA[2], Y HASHIZUME[3] And M KOSAKA[4]

SUMMARY

Many concrete structures, including bridge and viaduct piers, were severely damaged by shearing force exceeding the design seismic load in the 1995 Hyougoken Nanbu Earthquake (magnitude 7.2). Since the Earthquake, pier dimensions are tending to become oversized because of design using greater seismic load for a check. But it is not reasonable to design all piers against the standard of a rare major earthquake exceeding the ordinary seismic load. We performed 3 series of compressive shear tests to find a rational concrete reinforcements to prevent collapse of structures. Among a few successful arrangements, double reinforcement cages keep the load-displacement curve smooth up to the ultimate limit and the maximum residual strength. This makes it possible to maintain the shapes and frameworks of piers without collapse and to protect anyone on the bridge safely during a major shock, and possibly to use damaged bridges for emergency traffic and to perform temporary restoration work more easily.

INTRODUCTION

Many concrete structures in Kobe, including bridge and viaduct piers (Photos 1 and 2, Figure 1), were severely ruptured by shearing forces over the design seismic load in the 1995 Hyougoken Nanbu Earthquake (magnitude 7.2). Such collapses not only destroys the functions of structures but also takes the lives of people inside and on top of structures, and require excessive time and expense for reconstruction. Enormous losses of life and property actually occurred in Kobe.

If the damaged structures were to maintain their shapes or frames even under an anticipated large loads, it would be possible to save the lives of people inside buildings and on bridges. In the case of bridges and viaducts, it would be easier to perform temporary restoration work and to respond to refuge and rescue needs in early stages. If circumstance permitted, it would be possible to move directly into full-scale restoration work. We performed a series of loading tests for several types of rational concrete reinforcements to prevent collapse of concrete structures and to maintain their frames even in huge earthquakes exceeding the design load. Although it is natural for damage to be generated in structures by large forces over the design load, frames can be left standing by reasonable reinforcements that absorb the acting forces in plastic deformation as well as the work and frictional heat in the crushed concrete.

LOADING TEST AND SPECIMEN

It is very difficult to reproduce in the laboratory the damage that occurs to members due to shear force. For this reason, we adopted shear breakage in compression tests as the object of study, instead of using bending shear tests. The specimens were circular, square and rectangular columns. We call these experiments “compressive shear tests” (Photo 3 and 4). The broken state of the specimens was quite similar to damaged structures. In the

[1] *Construction & Environmental Engineering Laboratory, Hachinohe Institute of Technology, Hachinohe, Aomeri, Japan*
[2] *Civil Engineering Dep. , Hachinohe Institute of Technology*
[3] *Civil Engineering Course, Hachinohe Institute of Technology*
[4] *Civil Engineering Course, Hachinohe Institute of Technology*

tests, we measured not only the maximum value of the resistance of the specimens but also the residual resistance after destruction, and followed the relation between load and displacement.

Figures 2 to 4 show the arrangements of the reinforcements in the 3 types of columns. Each specimen had the same height (15 cm) and sectional area (1766 cm^2). The mix proportion of the concrete is shown in Table 1. The diameter of the axial reinforcements was 6 mm and that of the tie bars 3 mm. The load, compressed displacement and strain were measured with a pressure meter, dial gauge and strain meter. Following the maximum load, measurements were performed with a pressure meter and dial gauge.

MEASURED RESULTS OF COMPRESSIVE SHEAR TESTS

Figure 5 shows the load-displacement curves of tests on columns with tie bars as well as plain concrete columns for 16 kinds of circular column specimens. The curves indicate confining effect due to the number of tie bars and a sudden decrease in resistance after the maximum load. Figure 6 shows the load-displacement curves for specimens with bars crossing at the centre. These continuous curves show great residual resistance and the effectiveness of a number of bars. Figure 7 shows curves for columns with double steel bar cages as well as ones with a single bar at the centre. These are also continuous curves, showing greater residual resistance and the effectiveness of a number of axial bars and a smaller diameter cage, and even a single bar. The double steel bar cage can be prefabricated at the site and easily set inside outer reinforcements that are already composed, using a crane. This means that reinforcements at the sectional centre, which contribute slightly to resistance against bending moment, provide great residual resistance and smooth deformation after breaking of the column. Other specimens with bars crossing the centre show approximately the same properties. The measured maximum strain for the specimens was distributed in the range from 1,800 to 2,000μ.

For 12 kinds of square columns, Figure 8 shows the load-displacement curves for columns with tie bars only, single and double crossed bars, and 2 double steel cages, as well as plain concrete column. These curves show nearly the same effects as the circular columns. But the specimen with 5 tie bars showed similar properties to columns with double cages and crossed bars. This means that numerous strong tie bars provide increasing column ductility. The few discontinuities in the curves resulted from resetting of the dial gauges. The behaviour of specimens with a single bar were similar to crossed-bar specimens. The maximum measured strain was 2,000 to 2,800 μ.

Figure 9 shows the load-displacement curves of specimens with tie bars, spiral arrangement and plain concrete for 15 kinds of rectangular columns (aspect ratio 2:1). Almost the same effects are seen as the circular columns, which means that the effect of the tie bars is hardly exhibited in rectangular columns with a large aspect ratio. A spiral reinforcement arrangement is more effective than tie bars. Figure 10 shows curves for columns with transverse and diagonal arrangements. They are a little stronger than those with tie bars but do not exhibit good behaviours with circular and square shapes. Figure 11 shows curves with one and two single bars, and a double cage (in this case, a single net). The columns have almost the same properties as circular and square columns. Figure 12 shows curves for columns with ‡shape crosses and transverse arrangements connecting 4 additional axial bars. Although the‡cross is not good, the improved transverse arrangement exhibits preferable behaviour close to that of a double cage. This means that firm connection of reinforcements is important, although performing such work through the section is onerous. Many specimens with rectangular columns broke transversally and they were weaker than circular or square columns. The maximum strain was 1,500 to 1,800 μ.

DISCUSSION

It is economically impossible to protect all bridges and viaducts in the world from damage due to intense seismic force. Although seismic damage is inevitable to some degree, it should be possible to design structures that will maintain their shape after a severe main shock. If damaged structures continue to stand, the lives of people inside or on top can be preserved and restoration work may be made easier, depending on the damage. In order to absorb strong forces, the concept in Figure 13 is practical. Excess force is absorbed in work. Figure 14 shows a load-displacement curve of a square column with a double cage. The column broke under a load of 70 tf and at a calculated strain level of 5,000μ, corresponding to a displacement of 1.5 mm. The area of the curve after the maximum load, from 1.5 mm to 4.5 mm, is about twice the area before breakage (from 0.0 to 1.5mm). The value of 10 tf at 4.5 mm corresponds to 5.6 Mpa, which can sustain an ordinary load. The wide area after the breakage means that there was significant damping of vibration. Structures can thus endure larger earthquakes than estimated if they maintain their shapes during the main shock. We therefore examined the results of the compressive shear tests from this viewpoint.

Figure 15 to 17 show comparisons of circular, square and rectangular columns using different numbers of tie bars. As in Figures 5, 8 and 9, increasing the number of tie bars slightly increases the resistance but cannot prevent sudden collapse after the maximum load, except for 5 bars with a square column. A spiral arrangement is superior to tie bars but it cannot prevent sudden collapse and is not applicable because of the usage of strand. Tie bars are not effective with the most popular rectangular column because almost breakage occurs transversally. Other additional reinforcements along the face of the tie bars are not very effective.

The sudden collapse of specimens with tie bars depends on breakage of the central concrete, so reinforcement at the centre is very important. Figure 18 shows a comparison of load-displacement curves with cross bar reinforcements. Although the maximum resistance is less than with tie bars, the curves are continuous after breakage and have relatively high residual resistance, except for rectangular columns. The reason for discontinuity with rectangular columns is the weak connection with the tie bars. Other arrangements across the centre exhibited behaviour similar to that in Figure 18. Although the reinforcement at the centre of the section is a reasonable idea, the work of putting together reinforcements that cross at the centre is complicated and onerous to perform at the site.

To solve the above mentioned problem, a double cage reinforcement was devised. Its behaviour is illustrated in Figures 7, 8, 11 and 19. All specimens have continuous load-displacement curves and the highest residual resistance. Among these, an inner cage with a smaller diameter exhibited better behaviour than the larger ones. Reinforcements at the centre were effective even in the case of a single axial bar. Double cage reinforcement is a superior method for on-site work, since a prefabricated inner cage can easily be set in place using a crane, in spite of the greater amount of steel bars.

Through these tests, it was found that reinforcement against shear breakage in rectangular sections was problematical. The rectangular columns were weaker than circular or square ones. Since transverse breakage tends to occur, steel bar nets should be applicable in narrow spaces. The interval of the inner cage should be determined in consideration of the concrete work. To maintain the shape of structures, evaluation of residual resistance is very important. Maintaining residual resistance seems to depend on having an inner section surrounded with axial reinforcements.

CONCLUSION

Through 3 series of compressive shear tests, we found that it is possible to design concrete structures reasonably against excess seismic load using rational reinforcements, without increasing dimensions or apparent cost. Seismic damage due to earthquakes is inevitable but it should be possible to maintain the shapes and frames of structures during main shocks to save lives inside or on top and to avoid enormous investment. The main points found from the tests are as follows.

1. Since the maximum resistance is limited, reinforcement at the centre of the section is effective. By implementing this, smooth load-displacement curves and relatively high residual resistance can be obtained.

2. Tie bars surrounding axial reinforcements are useful up to the maximum load. However, they undergo sudden collapse after that. Numerous tie bars may prevent this phenomenon. Spiral reinforcements instead of tie bars exhibit better behaviour.

3. The newly-devised double steel bar cage is excellent for reinforcing the central section of the column. The inner cage can be prefabricated at the site and set inside the outer cage, which is already composed, with a crane. This method will prevent excessively onerous reinforcement work and shorten the schedule in spite of the greater amount of steel.

REFERENCE

Veletsos, A. S, Newmark, N. M,: Effect of inelastic behaviour on the response of single system to earthquake motion, Proceedings of Second World Conference of Earthquake Engineering, 1960

Table 1 Mix proportion of concrete

Water (kN)	Cement (kN)	Coarse sand (kN)	Fine sand (kN)	Coarse aggregate (kN)	AE agent (N)
1.65	2.99	6.36	1.67	10.07	0.88

Photo 1 Collapsed bridge pier

Photo 2 Collapsed viaduct pier

Photo 3 Compressive shear test (square column)

Photo 4 Compressive shear test (rectangular column)

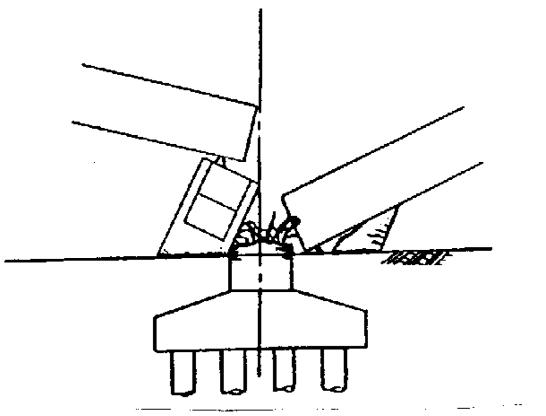

Figure 1 Details of collapsed bridge pier

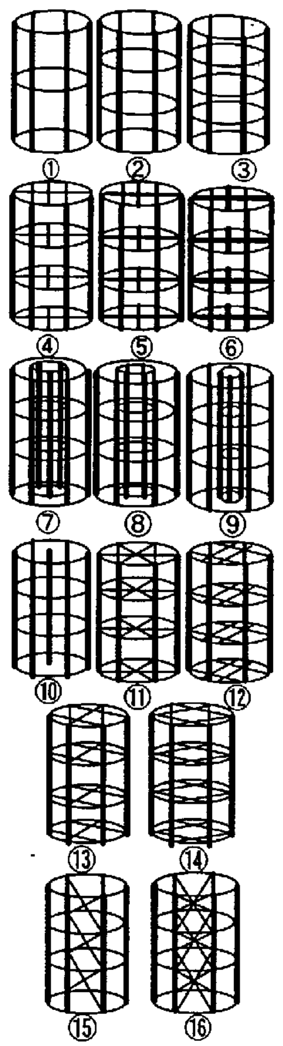

Figure 2 Circular column specimens

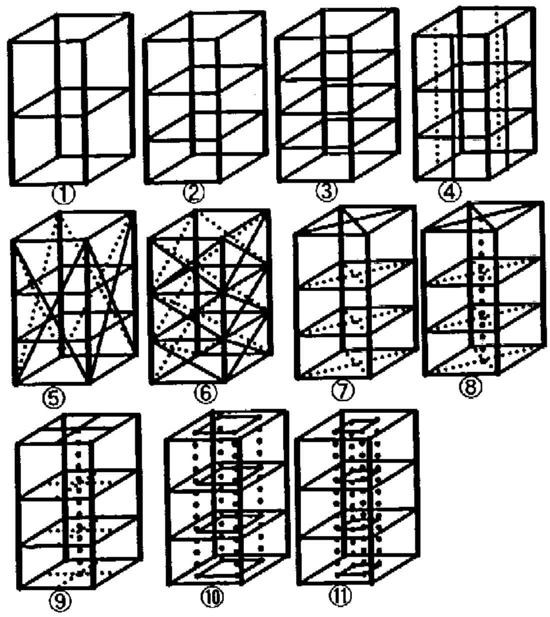

Figure 3 Square column specimens

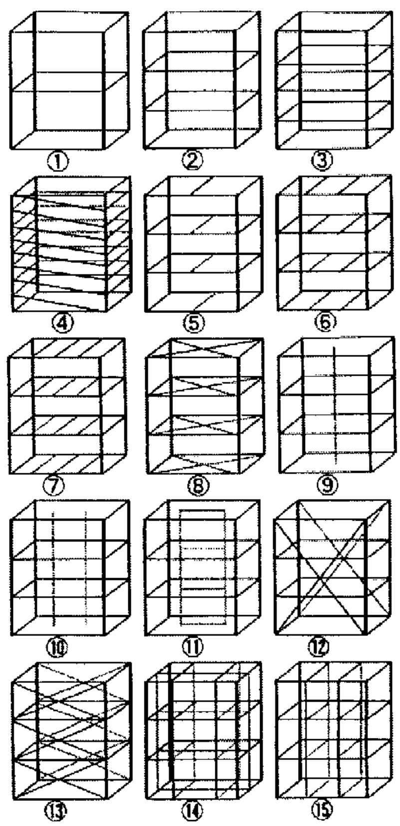

Figure 4 Rectangular column specimens

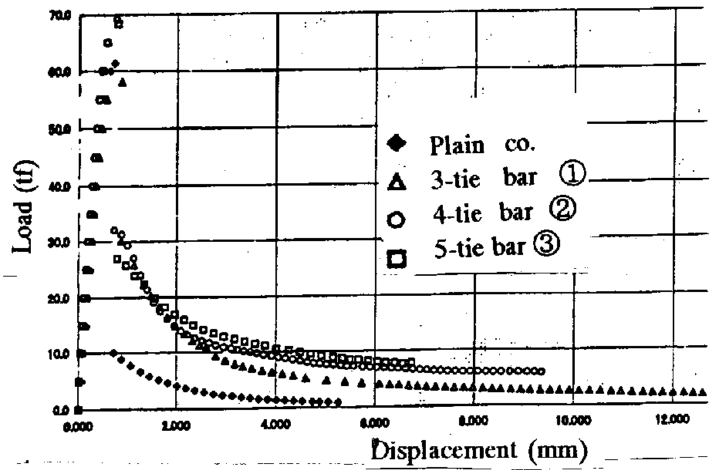

Figure 5 Load-displacement curve of circular columns with tie bars

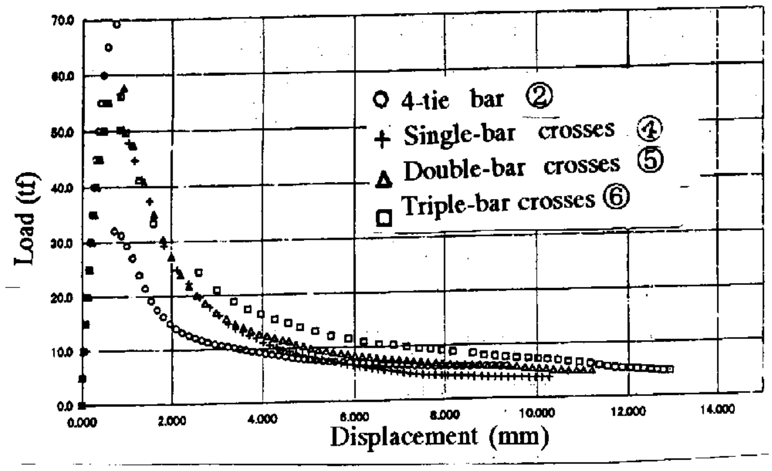

Figure 6 Load-displacement curves of circular columns with crossed bars

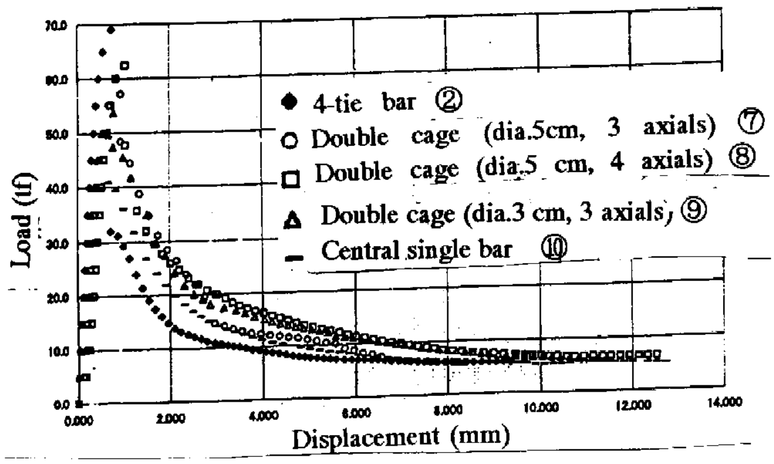

Figure 7 Load-displacement curves of circular columns with double cages

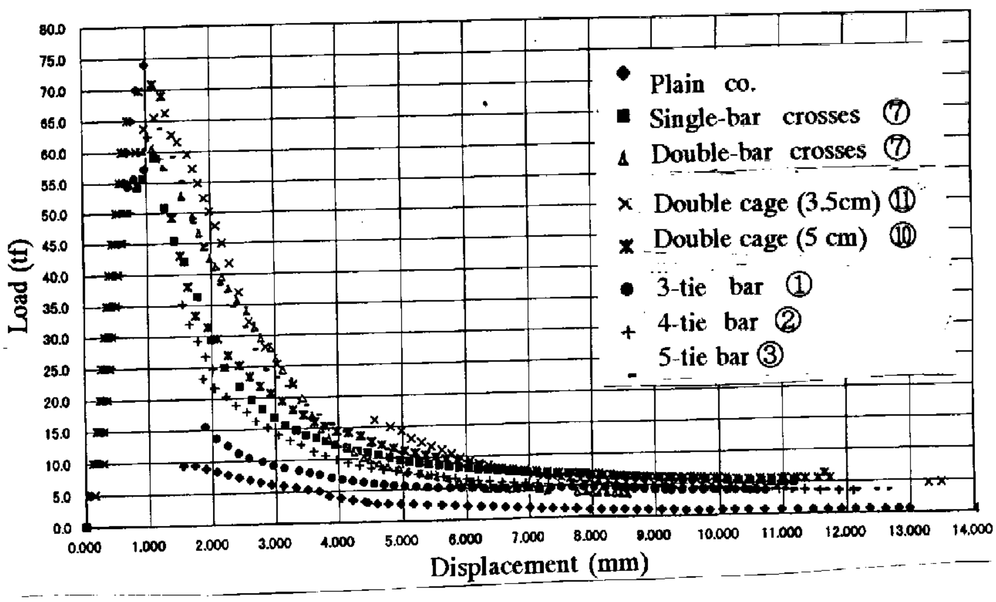

Figure 8 Comparison of load- displacement curves of square columns

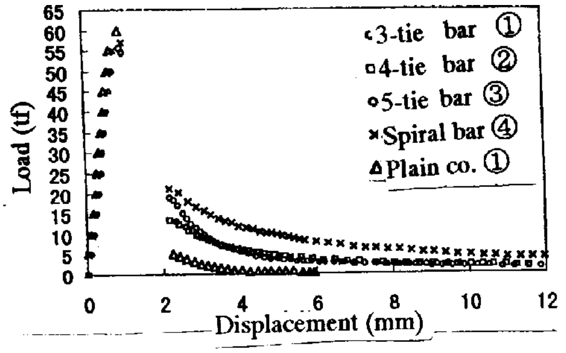

Figure 9 Comparison of load-displacement curves of rectangular columns with tie bars, spiral bars, etc.

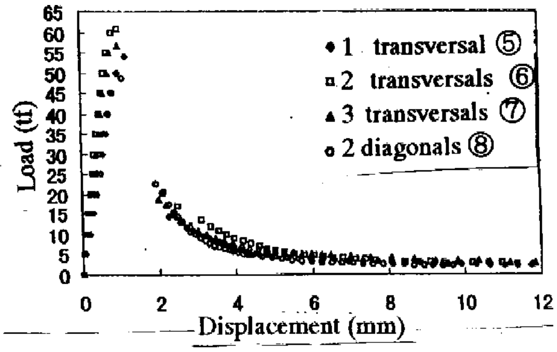

Figure 10 Load-displacement curves of rectangular columns with crossed bars

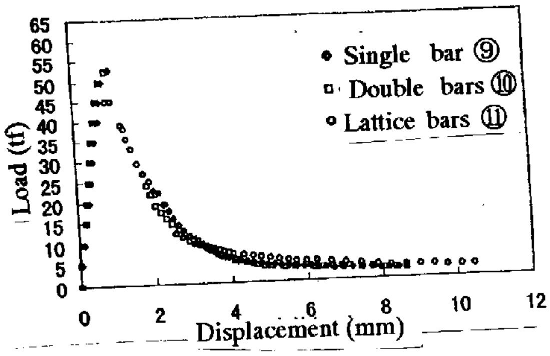

Figure 11 Load-displacement curves of rectangular columns with reinforcements at the centre

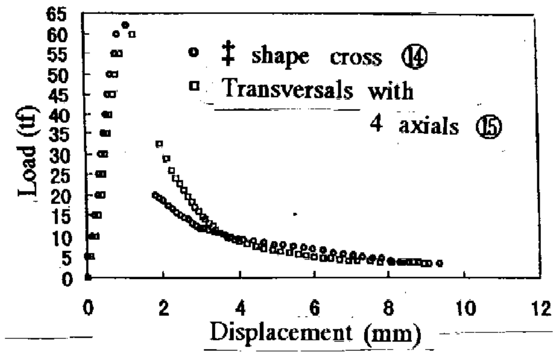

Figure 12 Load-displacement curves of rectangular columns with ‡ shape and improved crosses

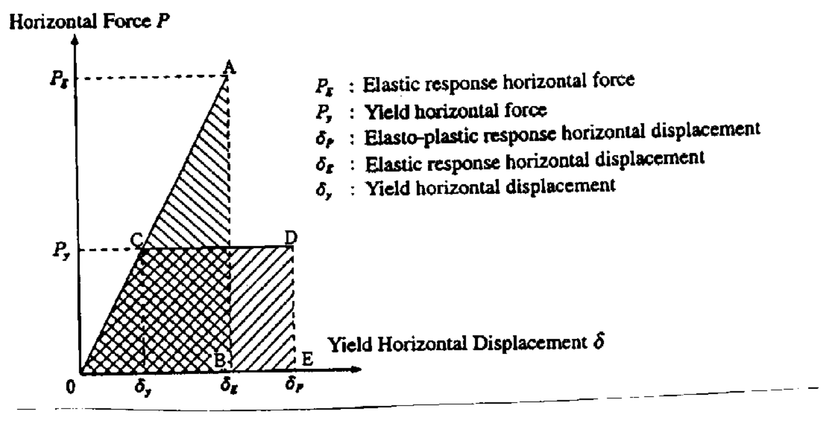

Figure 13 Elasto-plastic response displacement of a bridge pier

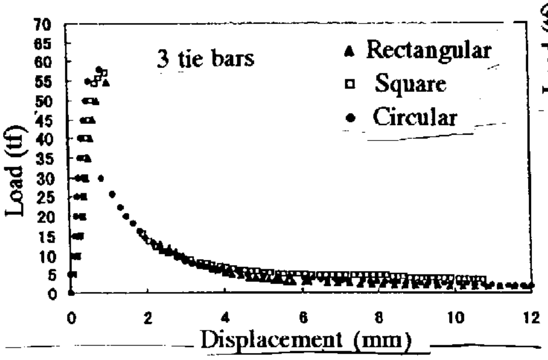

Figure 15 Comparison of reinforcement effect with 3 tie bars depending on column shape

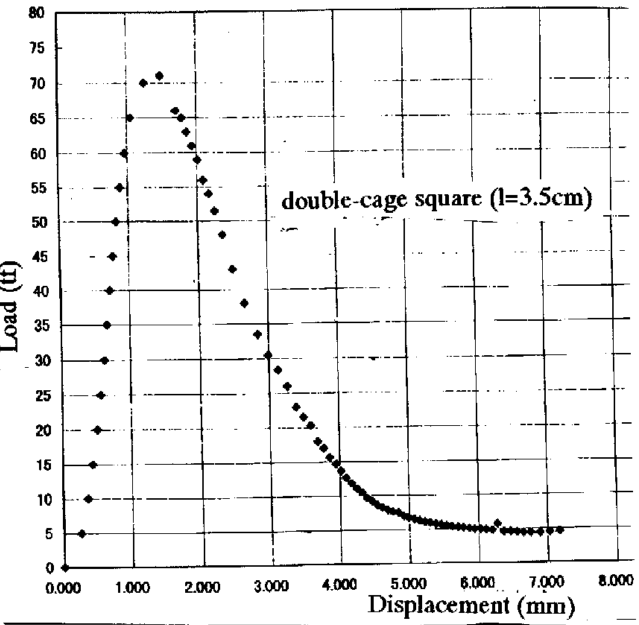

Figure 14 Load- displacement curve of square column with double cage reinforcement

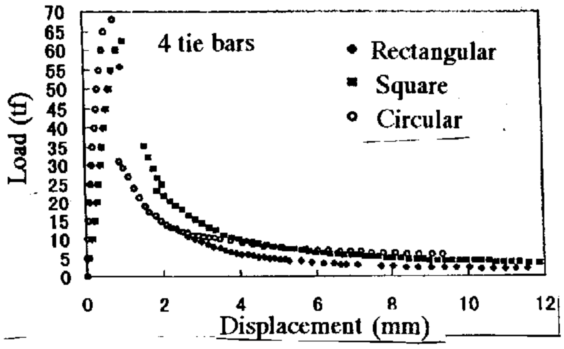

Figure 16 Comparison of reinforcement effect with 4 tie bars depending on column shape

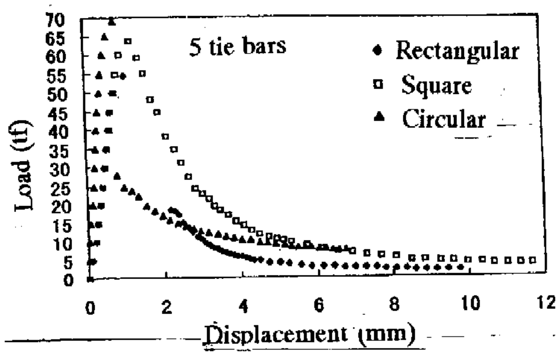

Figure 17 Comparison of reinforcement effect with 5 tie bars depending on column shape

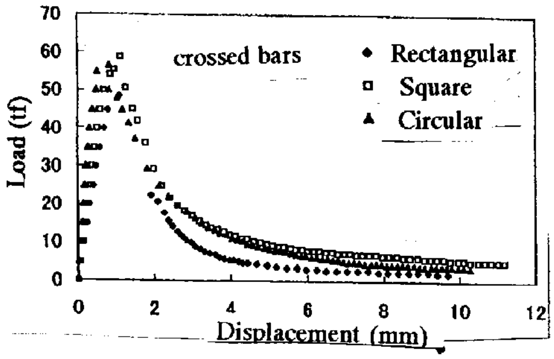

Figure 18 Comparison of reinforcement effect crossed bars depending on column shape

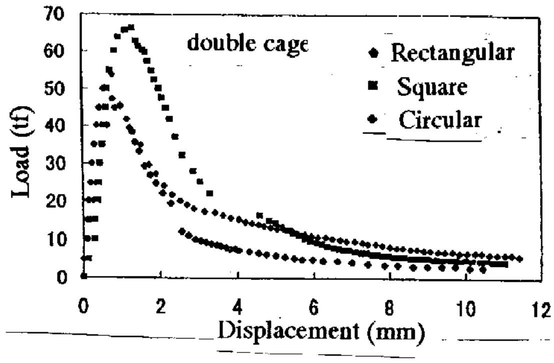

Figure 19 Comparison of reinforcement effect with double cages depending on column shape