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DESIGN AND EXPERIMENTAL RESEARCH OF MEGA--FRAME STRUCTURE USED FOR TALL RESIDENTIAL BUILDING

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ABSTRACT

Reinforced concrete mega-frame structure used for residential building has the advantages of more freedom for architectural composition; less consumption of reinforced concrete; lighter weight and lower cost comparing to conventional shear wall structure. Structural arrangement and analysis are shown by the design of an eleven storied residential building.
Experimental research on seismic behavior of two different mega beam-column joints has been conducted and analyzed.

KEYWORDS

R.C. mega-frame; structural behavior; mega beam-column joint; seismic test.

MEGA-FRAME STRUCTURE

Using spatial wall elements and large space between those vertical elements, different types of architectural planning can be composed(Fig.1). The vertical tubes and horizontal story structures spaced every 3-4 stories constitutes mege-frame structure. The aspect of the building can be varied in elevation.

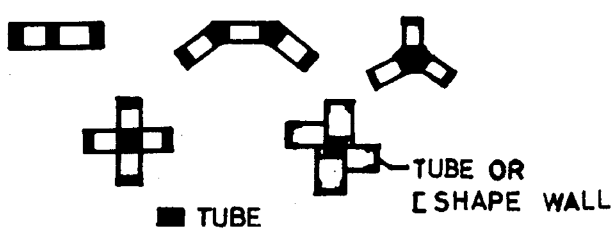

Fig. 1 Schematic plan of mega-frame structure

As an example an eleven storied residential building of rectangular plan is shown in Fig.2; Fig 3 and Fig 4. Spaces of 9.9x10.2m without beams and interior walls can be obtained for different variations of planning. In ground floor and basement large space can be obtained by dividing the rectangular tubes into coupled cores. Shops can be arranged.

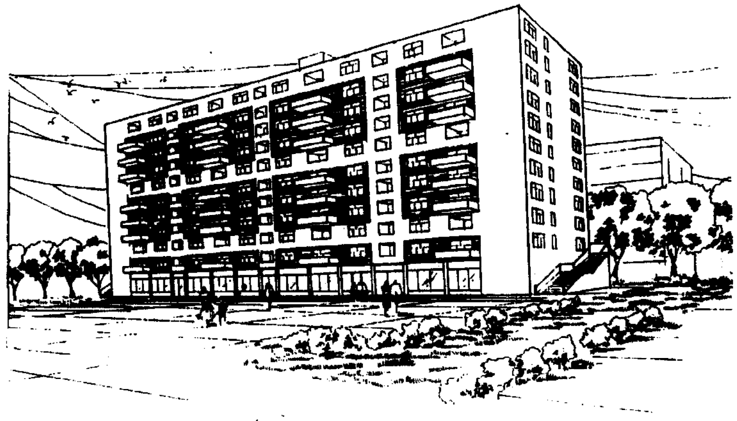

Fig. 2 Perspective view

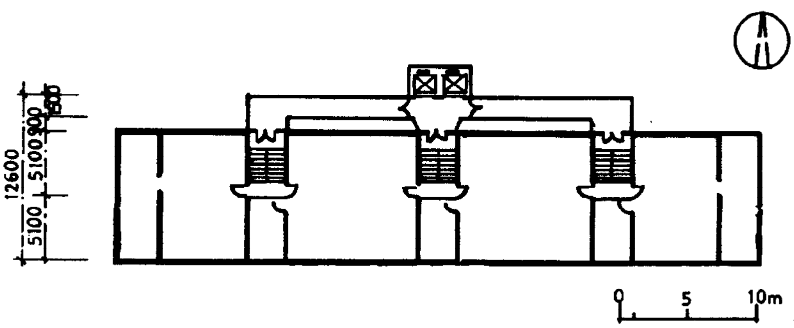

Fig.3 Typical floor plan

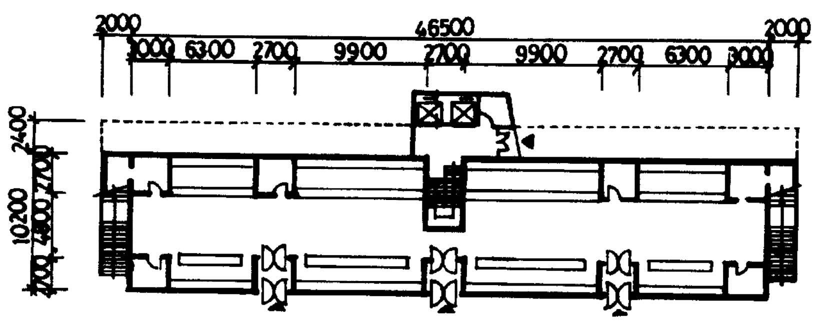

Fig. 4 Ground floor plan

Figure 5 shows the vertical arrangement of mega-frame and sub-frame.

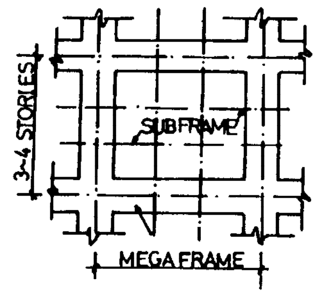

Fig. 5 Vertical arrangement of mega-frame unit

Behavior of Mega-frame Structure Under Vertical Loading And Earthquake Action

Fig. 6 illustrates the preliminary analysis of mega-frame shown in Fig. 2. Two different vertical loading conditions are considered in the analysis. In the first condition vertical loading is sustained simultaneously by mega-frame and sub-frame, it can be seen comparatively high tension will be carried by columns of sub-frame, another loading condition is considering junctions of sub-frame columns at the bottom of mega-beams are separated by construction joints in the first stage which includes structure load and partial construction load.

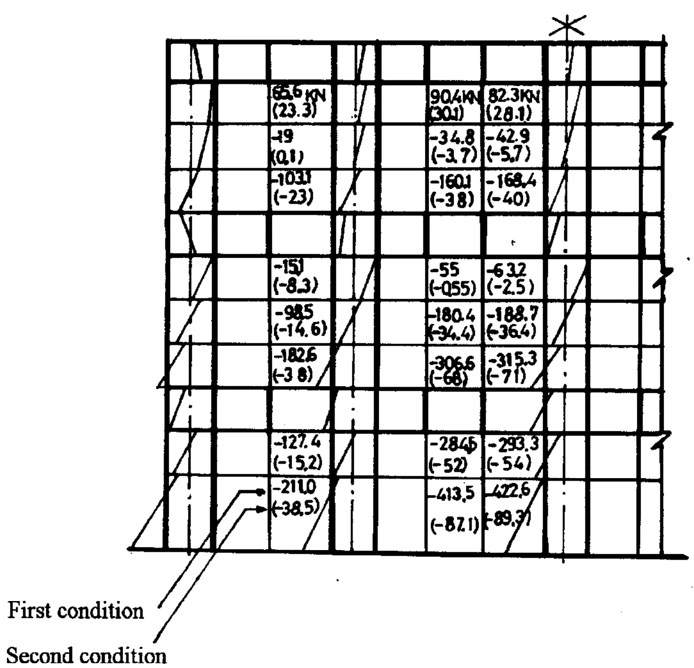

Fig.6 Column moment of mega-frame under earthquake action
(figures indicate axial loads of sub-frame column under vertical loading)

In the second stage the live load and remaining dead load will be carried by interaction of mega-frame and sub-frame, finally the addition of two loading stages shows lower tension in sub-frame columns(figures shown in the parenthesis) and larger moment carried by mega-beams. The actual progression of construction is difficult to be considered in the analysis, it seems to be more reasonable to analyze according to the second loading condition. Interaction of mega-frame and sub-frame is considered in the analysis of lateral force action, the moment diagram of mega-frame columns(Fig. 6) shows obvious inflection points. Restraining moments due to sub-frames are comparatively small.

Experimental Research On "Beam-Column Joint" Of Mega-Frame(MJ-1).

Similar to ordinary frame structure, seismic behavior of mega-frame is greatly affected by the strength and deformability of the junction of mega-beam and mega-column.
The joint panel may be solid wall or wall panel with opening. In order to study the seismic behavior and failure mechanism of the joint panel under most disadvantageous condition, mega joint specimen with opening at joint panel is tested. Test specimen simulates an interior joint of mega-frame. Hinge connections are provided at top and bottom of mega-column. Strength of concrete C40. Low cycle reversed loadings are exerted on both ends of mega-beam. Test specimen is shown in Fig. 7.

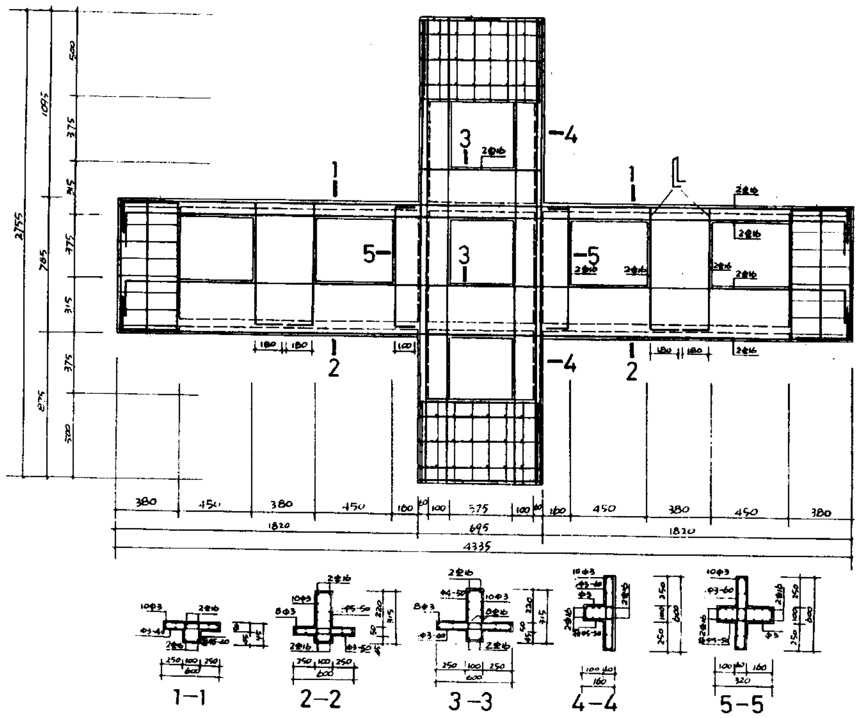

Fig. 7 Detail of test specimen MJ-1

Under loading of 50kN on beam, X cracks appear at joint panel, cracks develope following the increment of loading, especially at the lower part of joint panel. X cracks only appear at lower part of joint panel, one sided inclined cracks appear on both sides of the opening, this is owing to tension and compression are exerted on both sides of the joint panel under reversed loading of the beams, splitting cracks at the intersection of the beam and column cause one sided diagonal tension cracks appear on tension side alternatively. When beam load reaches 90 kN, failure occurs due to excessive shear deformation of joint panel. Confining effect of the flanges around the joint panel is characterized by the localization of shear cracks at the joint panel (fig.8)

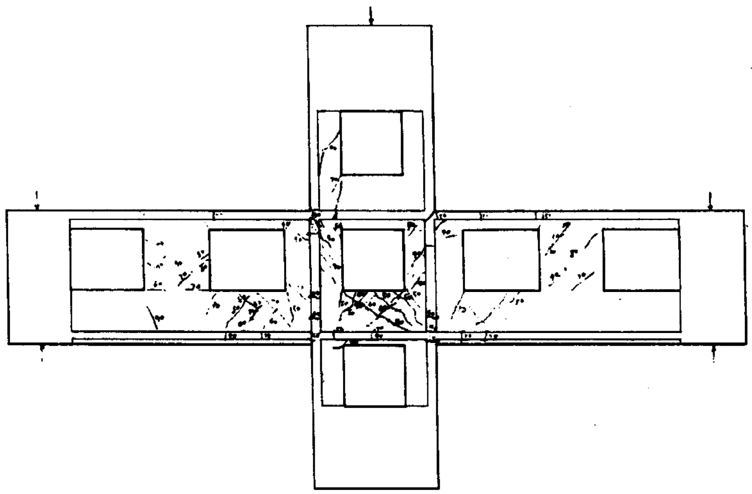

Fig.8 Crack pattern of test specimen MJ-1

The probable ways of improving the seismic behavior of mega beam-column joint may be increasing the thickness of joint panel or adding flange walls on both sides of mega-column (Fig.9)

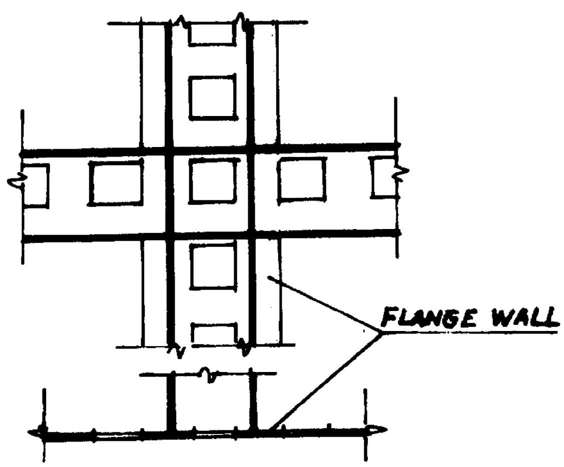

Fig. 9 Mega-column with flanges

Finite element analyses are carried out for the comparision of different schemes for strengthening joint panel against shear failure. Under the condition of 50kN loading at ends of beam and 200kN loading on top of column, principal stress diagrams are obtained by finite element elastic analysis using super-sap computer program. The max. tensile stress at lower part of joint panel (MJ-1) is approx. 4N/mm^2. Doubling the thickness of joint panel, the max. tensile stress at lower part of joint panel decreases to 2.4 N/mm^2 approximately. Adding wall flanges on both sides of mega-column (joint panel not thickened),the max. tensile stress at lower part of joint panel becomes 2.4 N/mm^2. The max. tensile stress at lower part of joint panel drops to 1.5N/mm^2 approximately by doubling both thickness of joint panel and flanges of mega-column. From the above analyses the scheme of adding flange walls on mega-column has the advantages of enlarging area of joint panel consequently reducing shearing stress in joint panel, strengthening the mega-column, reducing span of mega-beam and increasing rigidity of mega-frame.

Experimental Research on Beam-Column Joint of Mega-Frame .MJ-2.

Test specimen is shown in Fig.10

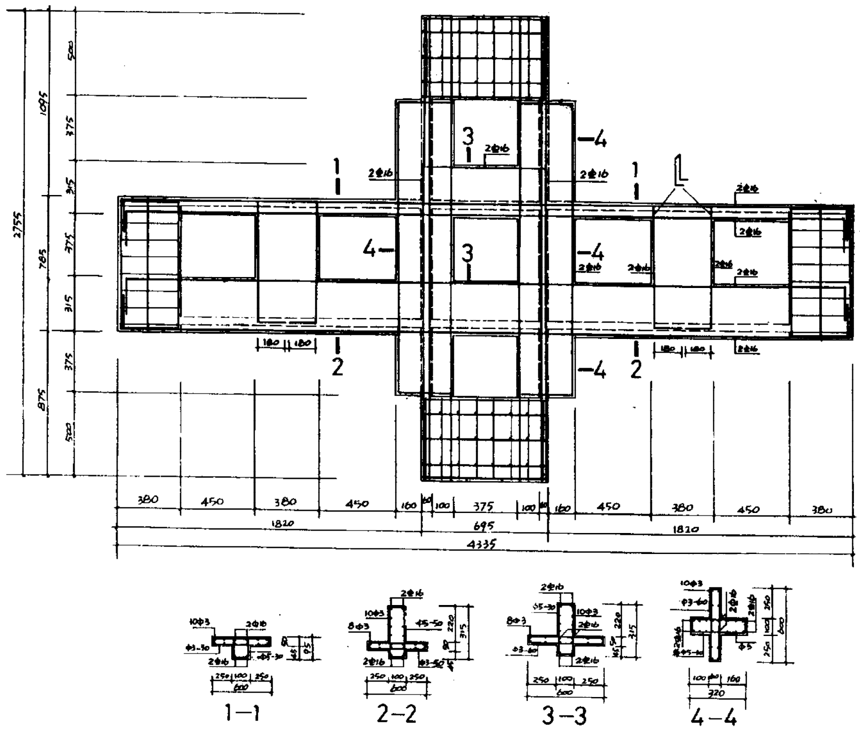

Fig. 10 Detail of test specimen MJ-2

Under loading of 40kN on beam very fine cracks are found at the lower part of joint panel, width of crack developes following the increment of loading, when loading on beam reaches 90kN X-cracks of width 0.6mm appear on both sides of the opening of joint panel, width of cracks at joint panel developes to 0.9mm, when loading on beam reaches 128kN. No failure indications of the joint panel are observed. Owing to the enlargement of joint panel the shearing strength of joint panel is much improved than that of MJ-1.

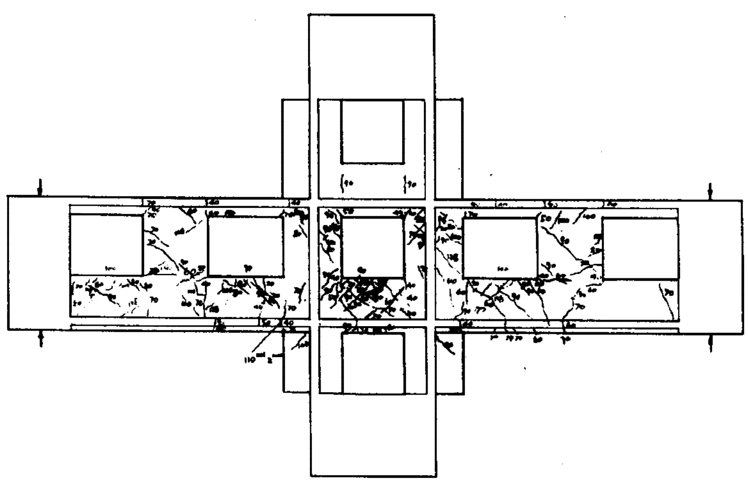

Fig. 11 Crack pattern of MJ-2

Evaluation of Shearing Stress in Joint panel of Mega-Frame

From the test results of MJ-1 and MJ-2, the stress distributions of longitudinal beam reinforcements on both sides of the joint are shown in Fig.12 and Fig.13.

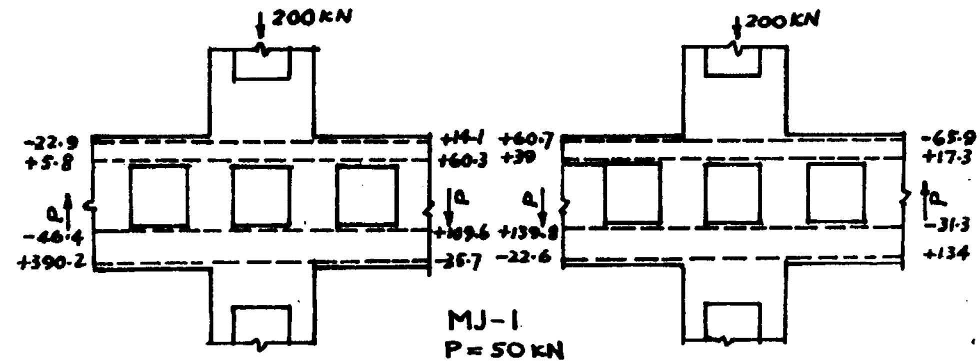

Fig. 12 Stress distribution of beam reinforcements N/mm^2

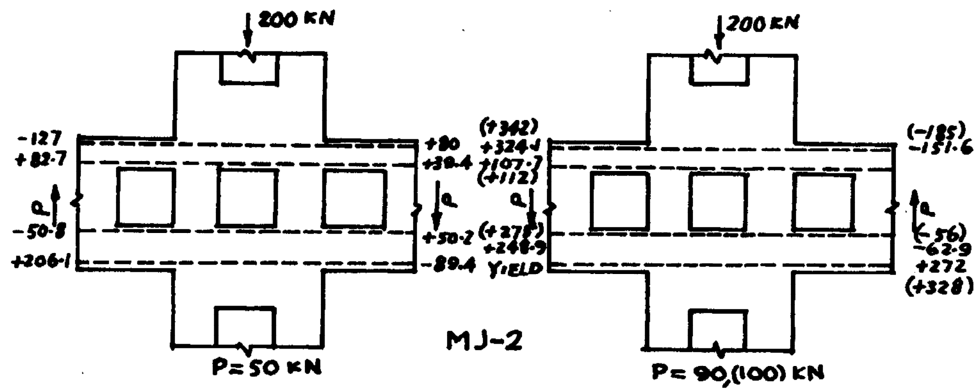

Fig. 13 Stress distribution of beam reinforcements N/mm^2

In Fig. 13, when P=100kN, yielding of longitudinal reinforcements at outerfaces of mega-beam occurs, the ratio of shearing stress in the lower member of mega-beam to design value of axial compressive strength of concrete is 0.2 which is the limiting value.

Based on test results the shearing stress of the joint panel can be evaluated by the following assumption: The joint panel should be designed to resist the shear force caused by the yielding of two critical positions marked by "Y" in Fig. 14. Forces acting on the joint panel are shown in Fig.14.

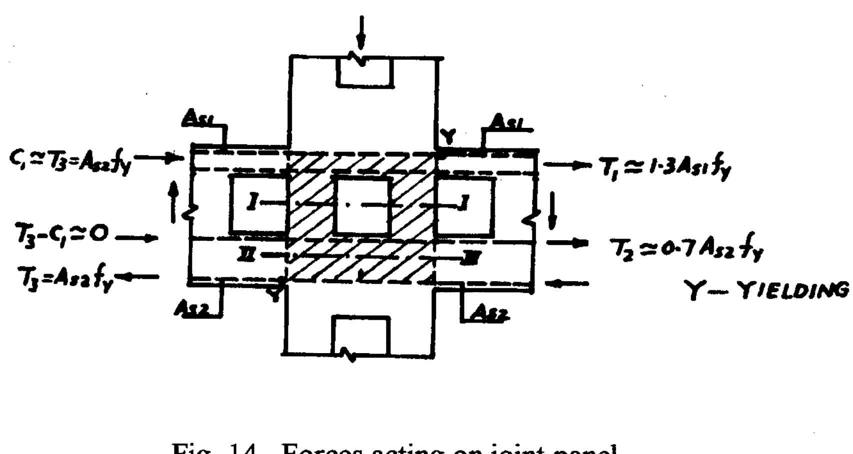

Fig. 14 Forces acting on joint panel

Under the condition of symmetrically reinforced beam members, the shear force at joint panel can be computed by the following expressions approximately:

$$V_{j(I-I)} = C_1+T_1-V_c=1.3\, A_{S1}f_y + A_{S2}f_y - V_c \quad (1)$$
$$V_{j(II-II)} = T_1+T_2+T_3-V_c=1.3A_{S1}f_y + 1.7A_{S2}f_y - V_c \quad (2)$$

$V_{j(I-I)}$ --shear force in section I-I
$V_{j(II-II)}$ --shear force in section II-II;
T_1---tensile force of longitudinal reinforcements in upper member of mega-beam;
T_2---tensile force of longitudinal reinforcement at top of lower member of mega-beam;
T_3---yielding force of longitudinal reinforcement at bottom of lower member of mega-beam;
C_1---compression in upper member of mega-beam;
A_S---sectional area of longitudinal reinforcement;
f_y----tensile strength of reinforcement;
V_c---shear force at interface of joint panel and upper mega-column.

In Fig.12 under the same loading stage tensile force in upper member of mega-beam is comparatively lower than that of MJ-2 shown in Fig.13, this is due to earlier deterioration of the joint panel.

Based on above expressions of V_j, necessary section of joint panel and reinforcements required can be computed. Shearing stress of joint panel should be limited, ratio of shearing stress to the design value of axial compressive strength of concrete should not be more than 0.2. Appropriate values of overstrength factor should be considered in computing tensile forces developed by longitudinal reinforcements of mega-beam.

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