A Study on Reinforced Concrete Slitted Shear Walls for High-Rise Buildings

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Experiments

Introduction There are now about 14 high-rise buildings in which the ductile slitted walls have been used in Japan. The features of slitted walls are described in references (1) and (2). The slitted wall has vertical slits at certain intervals at mid-height of a wall as in Fig.1. These slits are complete breaks not only in concrete but also in reinforcements so as to change the shear wall to a series of flexural wall-columns. The deflection capacity of slitted walls is so large that they are used in high-rise buildings, though their strength and rigidity decrease a little.

Characteristics of Slitted Walls The aseismic characteristics of slitted walls are as follows. 1) At low stress level, the rigidity of slitted walls contributes to keep small the lateral sway deflection of steel frame by minor earthquakes and winds. 2) At higher stress level beyond elastic limit, the slitted walls follow a large story displacement of steel frame with their ductility by severe earthquakes.

Additional Vertical Compressive Stress Slitted walls are apt to expand vertically with flexural tensile cracks when subjected to lateral shear displacement. In multi-storied structures the expansion is restrained by surrounding frames and walls, which produces additional vertical compression to the wall. Thus the wall has a merit in that the additional compression helps to reduce tensile reinforcements in the wall-columns. However, in conventional solid wall, pure shear deformation takes place and no additional compression occurs. This is the most different point of slitted wall from that of solid wall.

Test The main tests were performed applying medium vertical restraints. Photo.1 shows a general view of testing. A wall specimen is installed in steel frames and connected to the top and bottom frames with studs. The vertical frames and bars are arranged to give vertical restraints to the specimen. Fig.2 shows one of the examples of load-deflection curves of slitted walls under alternatively repeated cyclic loadings. As cracks developed the rigidity decreased and yielding occured in tensile reinforcements of wall-columns. The deflection angle even reached a large value of 0.01. The vertical restraint contributed not only to strength but also to crack recovery. The crack distribution is illustrated in Photo.2. When vertical restraint decreases both the strength and deflection are small. And when the wall is competely restrained vertically the strength increases but the deflection decreases with compressive failure at the ends of slits. A companion specimen of conventional solid wall showed large

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strength but small deflection angle and failed in shear as shown in Fig.2.

Analysis

Wall-columns of slitted walls are analyzed and designed for shear, vertical compression and flexural bending. Additional vertical compressive stress σ_n varies according to L/D ratio and stress level, and can be analyzed by the following empirical formula.

$$\sigma_n = k(L/D)\bar{\tau} \quad \text{.....(1)}$$

where, σ_n: additional vertical compressive stress
k: coefficient for vertical compressive restraint
L: slit length; D: slit interval
$\bar{\tau}$: average shear stress in the wall

The k values are obtained from experiments for yielding ky=0.7 and for ultimate ku=0.9, respectively. As the L/D lies between 1.8 and 2.5, the additional vertical compression generally falls between 1.25 and 2.25 times the average shear stress. The yield and ultimate stresses are calculated by common ultimate design formulae, using the additional compression by the above mentioned formula. The calculated values by minute analysis of beam theory are plotted by dashed lines with dots in Fig.2.

When these values are studied in detail, the relation between axial compressive stress σ_n and bending moment coefficient C of a wall-column can be shown as in Fig.3, where the dimensions and reinforcement ratio are given from an example of Fig.2. M in Fig.3 is the bending moment at slits' ends. As the shear stress in abscissa increases, the vertical compressive stress in ordinate increases proportionally to the above formula in the wall-columns of slitted walls. Thus the intersecting points C, Y and U are pursued with the increase of shear stress or story drift. The marks C, Y and U represent the tensile cracking, yielding and ultimate stresses by flexure respectively.

Concluding Remarks

In designing slitted walls the shear strength of the walls must be kept larger than the above mentioned bending strength in order to expect large ductility and deformability. Attention should also be paid to the slit construction. Generally a pair of asbestos sheets are inserted in the slit so as to construct flexural wall-columns and to deliver lateral compressive force between neighbouring wall-columns. The lateral compressive force is introduced by shear cracks and subsequent expansion of the wall-columns, as they are confined each other by slits. Accordingly, these asbestos sheets contribute to reduce shear reinforcements in a similar manner as tensile reinforcements.

Reference

(1) Kiyoshi Muto, EARTHQUAKE RESISTANT DESIGN OF 36-STORIED KASUMIGASEKI BLDG., Jan. 1969, proceedings of 4-WCEE (special report, Chile)
(2) Kiyoshi Muto NEWLY-DEVISED REINFORCED CONCRETE SHEAR WALLS FOR HIGH-RISE BLDG STRUCTURE, Oct. 1969, SEAOC Convention of Hawaii

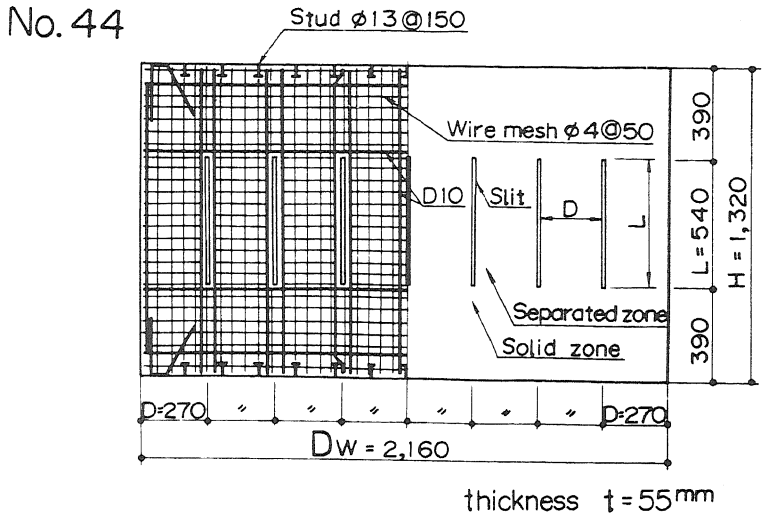

Fig.1
Layout of Slitted Wall

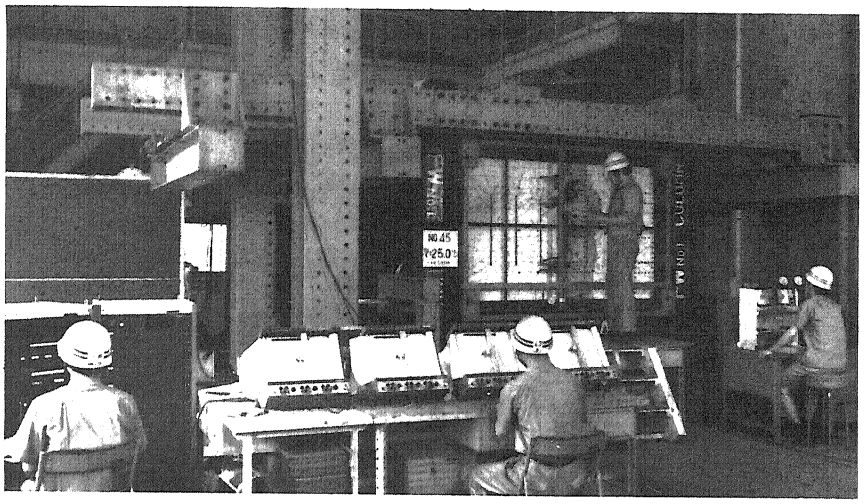

Photo.1
General View of Testing

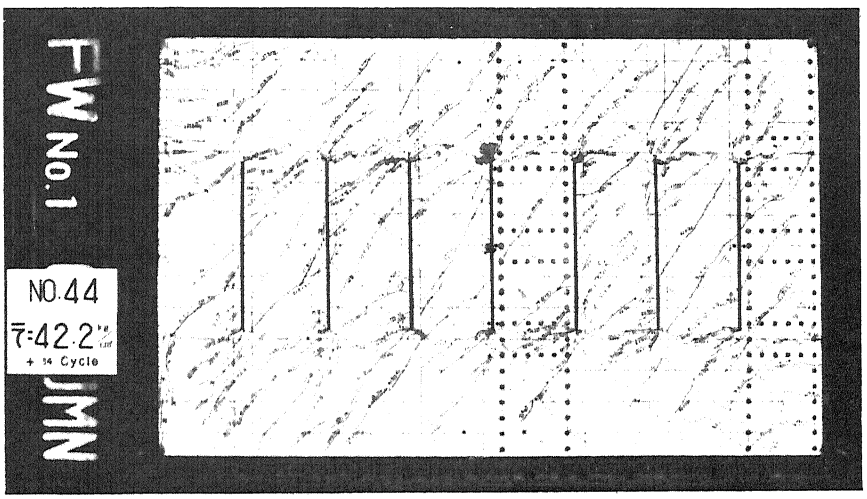

Photo.2
Crack Development of Slitted Wall

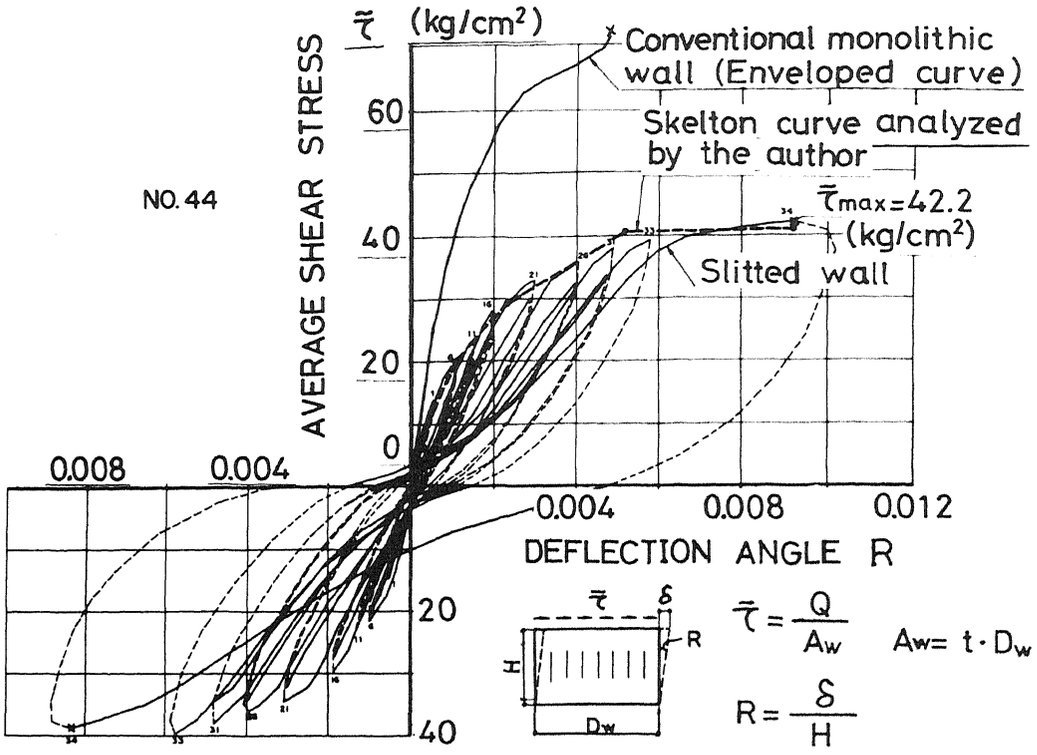

Fig.2 Load-Deflection Curves of Slitted Wall

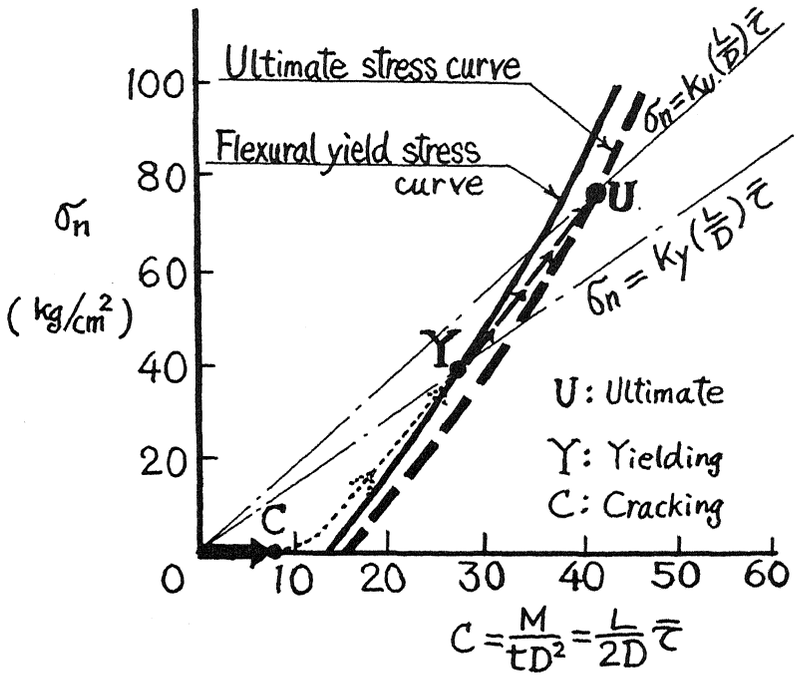

Fig.3 Interaction Curves of Normal Stress to Bending Moment in a Wall-column of Slitted Wall