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FUNDAMENTAL STUDY ON SEISMIC BEHAVIOR OF CELL LINERS

K. Takiguchi, H. Hotta, S. Nakamura and T. Irei

Tokyo Institute of Technology, Tokyo, Japan

ABSTRACT

This paper deals with shear behavior of cell-liners empirically. A new apparatus to measure the lateral displacement of the liner continously along its surface was manufactured by way of trial. As a result, it is effective to grasp a backling wave and the essential behavior of the liners are clarified.

1. INTRODUCTION

In nuclear related facilities, many concrete walls and slabs lined with thin stainless steel plates as liners in order to be ensured against the risk of accidental air-leakage due to a severe earthquake. The liners is forcibly deformed with the deformation of the concrete during earthquake. Their behavior can be broadly modeled to shear behavior of a rigidly supported rectangular thin flat plate prevented from deforming laterally in one divection. It is generally regarded as a pure mechanical problem, and its elastic or buckling behavior become analyzed numerically by a recent rapid advance of a computer techniques. However, the actual behavior of the liners is not sufficiently investigated, especially the lateral deformation is almost never measured actually or empirically in detail. It is important for estimating the safety of the liners to grasp not only a behavior computed but actual or empirical one.

The purpose of this study is to obtain basic data on a shear buckling and post backling behavior of a thin steel plate attached on a concrete wall subject to a shearing force experimentally. A new apparatus to measure a lateral displacement of a plate continuously scanning the surface in detail was manufactured by way of trial.

Table 1 List of specimens

Name of specimen	Testing Plate			Concrete
	Type	Size(mm)	Thickness(mm)	
L30-2P2.3	Double side	300×300	2.3	—
L30-CP1.6	Single side		1.6	○
L30-CP2.3			2.3	
L20-CP1.6		200×300	1.6	
L20-CP2.3			2.3	

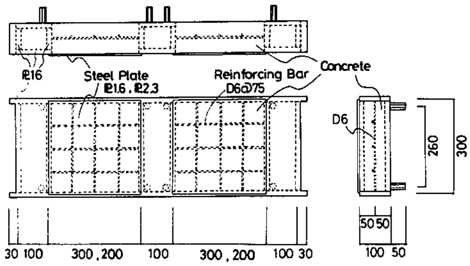

Fig.1 A typical specimen with concrete

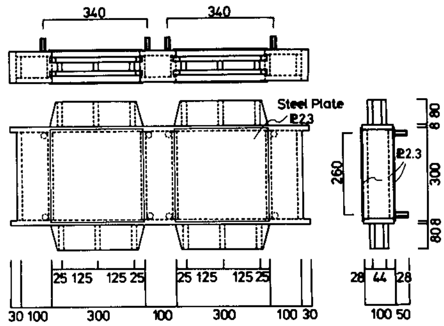

Fig.2 A specimen without concrete

2. TESTING PROCEDURE

2.1 Specimen and testing method

The five tested specimens are listed in Table 1. The typical specimen is deep SC composite beam consist of steel frame and concrete as web, as described in Fig.1. Concrete reinforced by a net of deformed bars(diameter:6mm and interval:75mm) is placed at the space surrounded by the steel frame consist of the steel plate whose thickness is 16mm, that is the square part of 300mm x 300mm in the figure. Steel thin plate whose thickness is 1.6mm or 2.3mm is attached on the concrete and welted to the steel frame. The size of the thin plate is also varied (20cm and 30cm). The depth of the beam is constant and 300mm. The length changes depending on the size of the plate.

Figure 2 shows another specimen. In order to compare the behavior of the plate with the specimens above mentioned, concrete is not placed in the specimen. A couple of steel plates which are 2.3mm thick are welded to the both sides of the steel frame. The upper and the lower steel flanges are strengthened as shown in Fig.2 as to the specimen without concrete.

The mechanical properties of the steel plates and the concrete are shown in Tables 2 and 3. The standard classification of the steel is SS400, and the strength of the concrete is about 360kg/cm^2. Reversed cyclic concentrated load was applied to the center of the simply-supported specimen by means of the apparatus as shown in Fig.3. The shear deformation, the literal displacement and the strain in a direction of 45° from the loading axis of the plate were measured, increasing the load stepwise.

Table 2 Mechanical properties of steel plates

		PL16	PL1.6	PL2.3
Actual thickness (mm)		16.32	1.59	2.22
Yield strength (t/cm^2)	upper	3.06	3.35	2.83
	lower	2.91	3.20	2.60
Tensile strength (t/cm^2)		4.61	4.32	3.67
Elongation (%)		24.8 - 27.8	26.9 - 33.6	36.5 - 37.4
Poisson's ratio		0.29	0.28	0.30

Table 3 Mechanical properties of concrete

	L30-CP1.6,CP2.3	L20-CP1.6,CP2.3
Age (day)	28	220
Compressive strength Fc (kg/cm^2)	362	368
Splitting tensile strength (kg/cm^2)	27.8	23.9
Fc/3 Secant modulus (10^5kg/cm^2)	3.4	———
Strain at the maximum stress (%)	0.24 - 0.27	———

Diameter and height of cylinder : 10cm × 20cm
Curing : in air

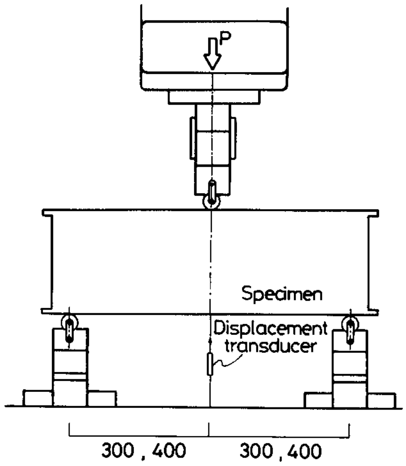

Fig.3 Testing Method

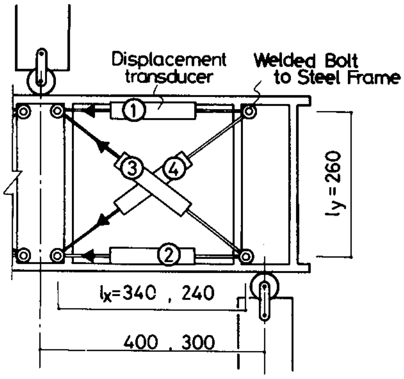

Fig.4 Measuring System of shear deformation of the liner

2.2 The measuring system of the shear deformation of the plate

The measuring system of the shear deformation of the plate is illustrated in Fig.4. Four long bolts are welded at each corner of the steel frame, and the distances between each pair of them are measured by four displacement transducers. The distance between two bolts being vertical each other is assumed to be constant, l_y=260mm. The initial distance between two bolts being horizontal each other is l_x=340 or 240mm, which changes depending on the size of the lining plate. The whole displacement, which consist of the ones due to bending and shearing, can be calculated from the data oftained by the displacement transducers and the above assumption. The shear deformation of the plate can be calculated, taking the displacement due to bending from the whole displacement, and given by the following equation;

$$r=(l_4-l_3)\ /(2\cdot lx\cdot ly)-(l_2-l_1)/(6\cdot ly) \qquad (1)$$

where l_1,l_2,l_3 and l_4 are the distances between two bolts measured by the displacement transducer ①, ② , ③ and ④ shown in Fig.4, and l_D is the diagonal length ($=\sqrt{lx^2+ly^2}$). The first term of eq.(1) represents the whole displacement of the beam and the second the one due to bending. The curvature of the beam is assumed to be in proportion to the bending moment in the calculation of the displacement due to bending.

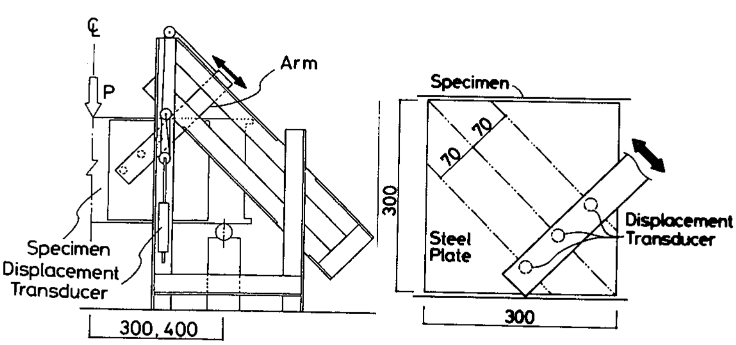

Fig.5 Measuring apparatus of lateral displacement of the liner

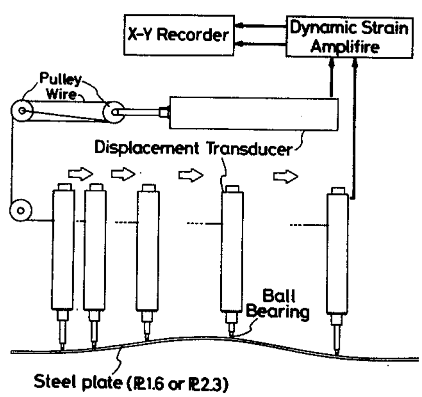

Fig.6 Outline of the measuring system of lateral displacement

2.3 The measuring system of the lateral displacement of the lining plate.

The measuring apparatus is illustrated in Fig.5. The arm on which three displacement transducers are set perpendicular to the lining plate can slide along the diagonal line of the plate. The sliding distance of the arm and the roughness of the surface of the plate measured by the displacement transducers, are amprified by a dynamic strain amprifire and the sliding distance versus the roughness curve are directly and continuously obtained by a X-Y recorder as shown in Fig.6. As shown in Fig.5, the roughnesses along the diagonal line and along two lines which is parallel to the diagonal line and 50mm far from it were measured at the same shear deformation of the lining plate. This system can measure the roughness of 0.001 mm of the plate. The initial inperfection of the plate can be also measured.

3. TESTING RESULTS

Load versus shear deformation curve and lateral displacement of lining plate at several levels of the shear deformation of the typical specimen with concrete are described in Figs.7 and 8. Those without concrete are shown in Fig.9. As for all specimens with the concrete, a diagonal crack at the concrete surface along the diagonal line was observed at the shear deformation of about 0.02 rad at first, and other cracks occurred parallel to the first observed one according to the increase of the shear deformation of the plate. Several cracks were observed at an interval of about 5cm at the shear deformation of 0.01rad, which was the reversal point of the positive loading. The occurrence of those cracks cause the degradation of the stiffness, but the strength. During the positive loading, the buckling of the plate was observed only in the specimen with the plate which was 1.6mm thick and 30cm x 30cm in size.

During the negative loading, the diagonal cracks occured parallel to another diagonal line at first, but the strength degradation was not recognized, similar to the positive loading. The concrete was failed due to the compression at a the shear deformation of -0.15 rad for all specimens with the concrete, and the specimens exhibited the maximum strength at that time. The lateral deformation of the plate also increased rapidly at that time. The lining plate endured the shear force by the diagonal tensile stress after the failure of the concrete. Finally, the upper and lower steel flange plates yielded due to bending near the center between the loading point and the supporting point.

As for the specimen without the concrete, the buckling of the plate was presumed to start at the shear deformation of 0.001rad, because the lateral displacement rapidly increased at that time. Because the plates still endured the shear force by the diagonal tension, the strength did not degraded by the buckling of the plate. After the buckling, the strength increased by reason of strain-hardening of the plate.

The initial inperfection of the lining plate was about 0.5mm in the maximum lateral displacement for all specimens. It was observed that the plate deformed in one direction because of the existence of the concrete. The direction of the buckling wave was about 45° from the loading axis for all specimens. The lateral displacement of the plate of the specimen without concrete was obviously larger than the ones with concrete at the same shear deformation, as shown in Figs. 7-9. The apparatus newly developed fulfilled its function sufficiently. It is effective to understand the lateral displacement of thin plate in detail.

Figure 10 shows the relationships between the lateral displacement, which is

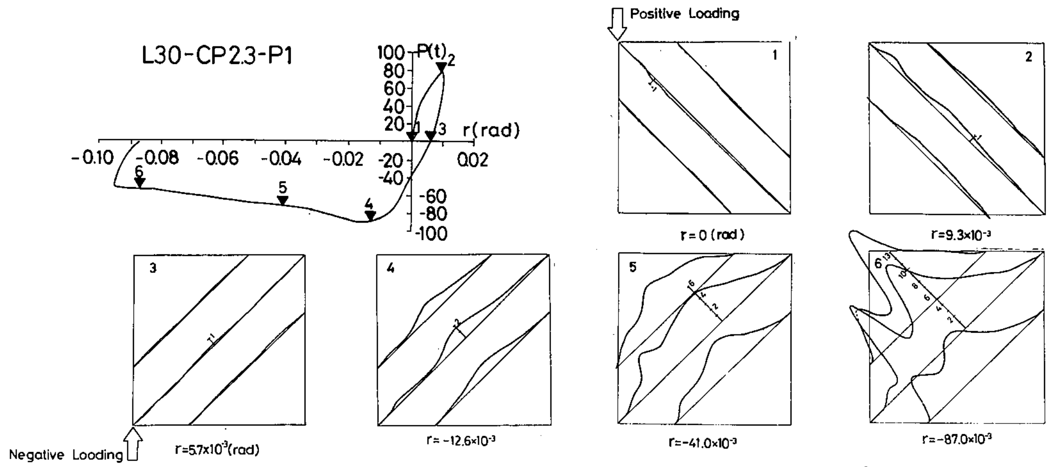

Fig.7 Load versus shear deformation curve and several configurations of lateral displacement

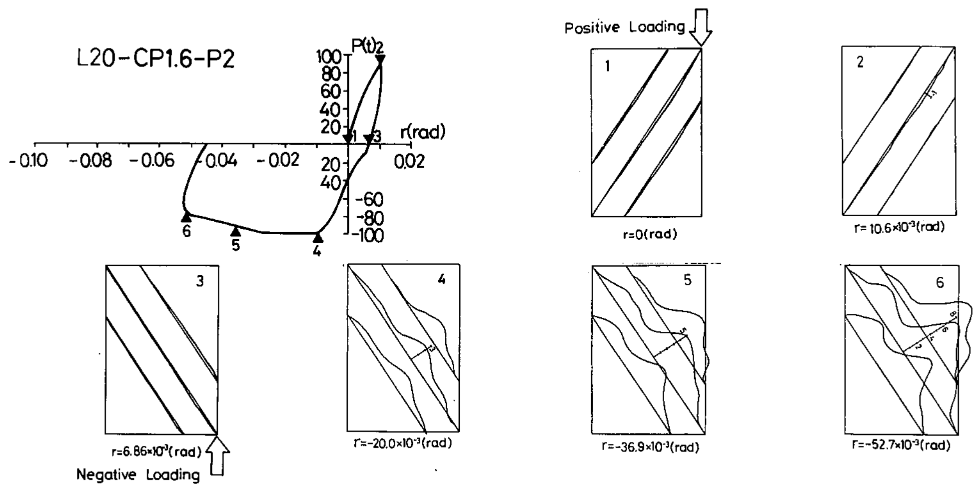

Fig.8 Load versus shear deformation curve and several configurations of lateral displacement

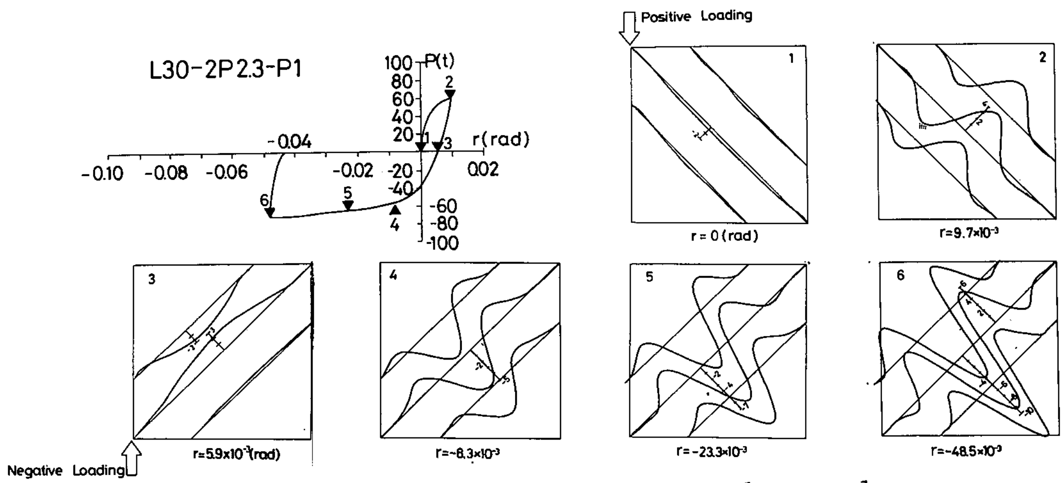

Fig.9 Load versus shear deformation curve and several configurations of lateral displacement

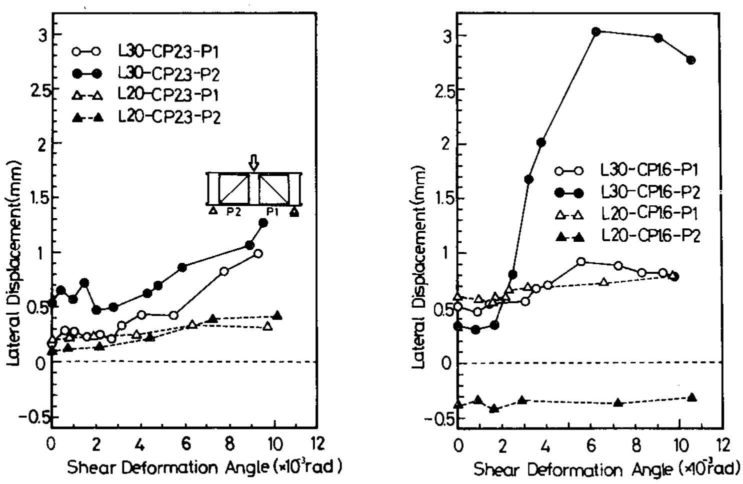

Fig.10 Relationships between lateral displacement and shear deformation of the liners

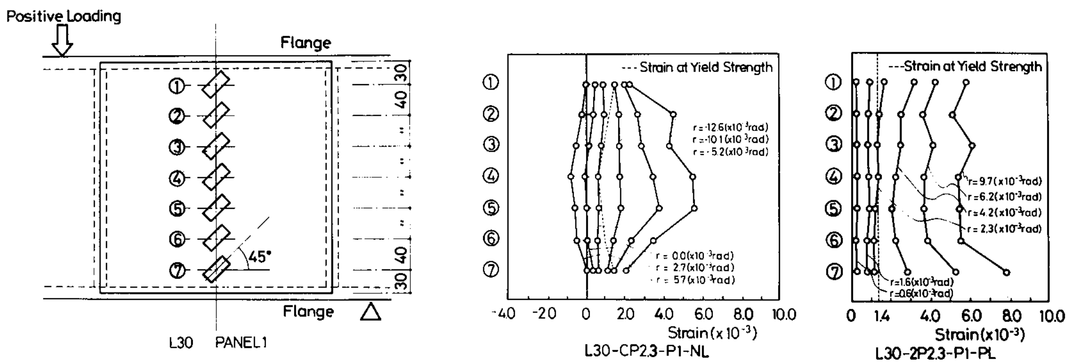

Fig.11 Distribution of diagonal tensile strain

the maximum ampritude of the buckling wave, and the shear deformation of the plate for the specimens with the concrete. If the plate is anchored at an interval of 30cm and more than 2.3mm thick, the maximum ampritude of the lateral displacement can be limited to 1mm at the shear deformation of 0.01rad which is the maximum deformation from a designed point of view.

The strain gauges were put on the hidden surface of the plates as shown in Fig.11 and the distributions of the diagonal tensile strain of the plates were measured. The result of the specimen with the concrete is described in the left figure, and the one without the concrete in the right figure. The distribution of the strain is not uniform as to the specimen with the concrete. The strain near the center becomes higher than the one at the boarder for the reason that concrete cannot restrain the steel plate which is the part of the steel frame from deforming inside because of the tension of the thin plate in a vertical direction. All testing plates yielded by the diagonal tensile stress until the shear deformation became 0.01rad.

4. CONCLUSIVE REMARKS

An apparatus to measure a lateral displacement of thin steel plate under a shearing force continuously along the surface was manufactured by way of trial. Several buckling behaviors measured by means of this apparatus are detailed in this paper.