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Seismic Shear Response of Slab with Distributed Mass
(Linear-elastic Structure)

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INTRODUCTION

In common, a slab for in-plane shear due to seismicity might be designed against a difference of adjoining bays' displacements and the slab stiffness for in-plane shear. Therefore no influence of mass distributed on the slab might be considered. The investigation of seismic behavior for distributed mass system had hardly been conducted. Then objectives of this study are: 1) to obtain fundamental information about local shear response for the distributed mass system of linear-elastic structure by time history analysis, 2) to propose a useful fundamental formula for prediction of the maximum local shear response in serviceability limit state design.

ANALYTICAL MODELS

Consider a frame with 1×2 spans such as previous researches[1)2)], according to its symmetry, a simplified model used to analyze in this study consists of two bays with a span (Fig. 1). The structure has a linear-elastic bay restoring force and story drift relationship as well as the slab. A constant k_1 means a ratio of stiffness of bay 1 K_1 to a sum of two bays' stiffnesses K_1 and K_2. The ratio is the following

$$K_1 = 2K_2 \qquad \therefore k_1 = \frac{K_1}{K} = \frac{2}{3} \qquad \text{where} \quad K = K_1 + K_2$$

This analytical model assumes the following:

a) Uniform mass distribution on the slab which could be expressed by Table 1 and Fig. 1
b) Each mass can move unidirectionally same as the seismicity.
c) The each bay is expressed as a mass supported by a shear spring which corresponds to its story drift.
d) Similarly the slab is expressed as 6 masses connected with 7 shear springs K_f' which correspond to its in-plane shear deformation. The springs have linear elastic behavior.

The variable structural characteristics in the analytical investigations include the following.

k_f : Slab shear stiffness ratio defined as a ratio of the entire slab stiffness K_f (Fig. 1(b)) to a sum of stiffness of supporting bays K $\quad k_f = K_f / K = 0.1 \sim 1000$

T_0 : Natural period when the slab is rigid
0.33, 0.67, 1.00 (sec)

m_1 : Mass ratio of the bay 1 to a sum of mass of the system

$$m_1 = M_1 / M = 0.50,\ 0.67,\ 0.80$$

where $\quad M_1 = \sum_{i=1}^{4} m_i', \quad M = \sum_{i=1}^{8} m_i', \qquad m_i'$: distributed mass

The distributed mass $m_1' \sim m_8'$ can be seen in Table 1. For comparison, a lumped mass system might be also used.

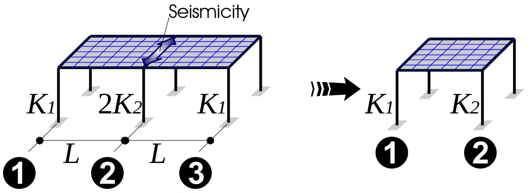
Applied unidirectional seismic waves are the EL Centro NS (1979) scaled such that its PGV (Peak Ground Velocity) matched 50 kine and the BCJ level-2 (1994). The integration is performed with a two percent of critical damping to the initial stiffness of the bays.

ANALYTICAL RESULTS

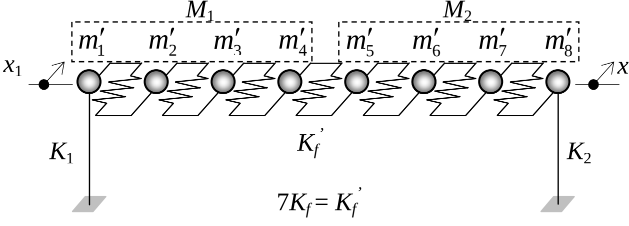
Fig. 2 indicates story drift time histories for BCJ with k_f of 1.0. Whenever the maximum local shear response is generated for slab stiffness ratio k_f of 1.0 or greater, the both bays' story drift displacements are always their respective approximate peak values in the cycle. Although the analytical results in case of T_0 = 0.67 with BCJ are illustrated here, the entire results including three different values of T_0 with two different waves, have found that the natural period and the wave hardly affect the slab shear response behaviors. Fig. 3 displays mass displacements and local shear distribution in the slab for BCJ when maximum local shear response occurred. The displacement distribution is not linear. And dynamic

Table 1. Mass distributions

m_1	0.50	0.67	0.80
M_1	0.50	0.67	0.80
$2M_2$	1.00	0.66	0.40
m'_1	0.125	0.4225	0.65
$m'_2 \sim m'_8$	0.125	0.0825	0.05



(a) Frame structure



(b) Analytical model

Figure 1. Frame structure and analytical model

分散質量を有する床のせん断応答（弾性架構）

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shear response variation along the axis normal to the direction of seismicity can be seen. The shear distribution is approximately proportional to the distance from the bays. That means inertial force applied to the mass on the slab resulted in these behaviors. From these facts the inertial force of mass on the slab could be thought transferred to the nearer bay. These findings could not be obtained by the lumped mass system. As shown in Fig. 4, it is apparent that the lumped mass system could underestimate the maximum local shear response in the slab with the distributed mass. In this figure, $V_{f\,\max}$ and MS_A designate maximum slab shear response and a sum of story shear response of the bays, respectively.

PREDICTION OF SHEAR RESPONSE

Predictable formulae of the shear response based on balance of static force for the lumped mass system were already reported as 1st terms of right side of following equations respectively[1)2)]. Assume that inertial force of the mass might be transferred to nearer bay, Eqs. (1) and (2) are proposed here. Considering practicality and convenience of the seismic design procedure, Eq. (2) is preferable for prediction of the maximum local shear.

$$V_{f\,\max} = \frac{k_f \left| m_1 - k_1 \right|}{k_1 \left(1 - k_1 \right) + k_f} MS_A + \max\left(\sum_{i=2}^{n/2} m_i', \sum_{i=n/2+1}^{n-1} m_i' \right) S_A \qquad (1)$$

$$V_{f\,\max} = \left| m_1 - k_1 \right| MS_A \qquad + \max\left(\sum_{i=2}^{n/2} m_i', \sum_{i=n/2+1}^{n-1} m_i' \right) S_A \qquad (2)$$

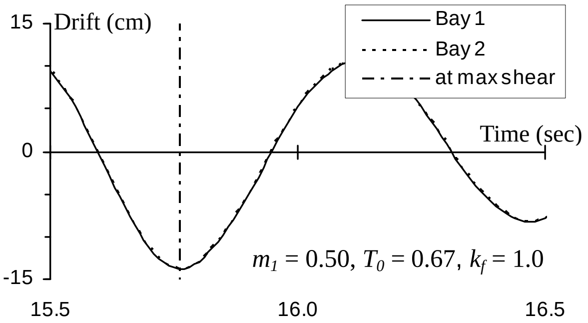

Figure 2. Story drift time histories at maximum slab shear

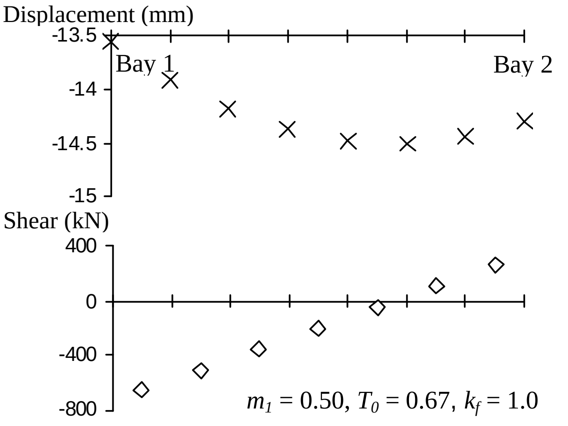

Figure 3. Distributions of displacement and shear

where n and m'_i designate number of mass and distributed mass respectively, S_A designates design spectral response acceleration.

Fig. 5 indicates maximum local shear response comparisons between analytical and predicted values for the distributed mass. For the slab stiffness ratio k_f of 3.0 or greater, increasing the value of k_f could not influence the analytical slab shear response. By taking account for inertial force applied to the mass not only on the bays but also on the slab, in addition to difference of the story drift between two bays of both sides of the slab, the maximum local shear response in the slab could be predicted appropriately by Eq. (1). When the slab stiffness ratio k_f is 3.0 or greater, Eq. (2) is also available for the prediction.

CONCLUSIONS

a) The distributed mass system showed dynamic shear response variations along the axis normal to the direction of seismicity.

b) The lumped mass system might underestimate the maximum local shear response for the distributed mass system.

c) The maximum local shear response in the slab with the distributed mass could be predicted appropriately by newly proposed formulae.

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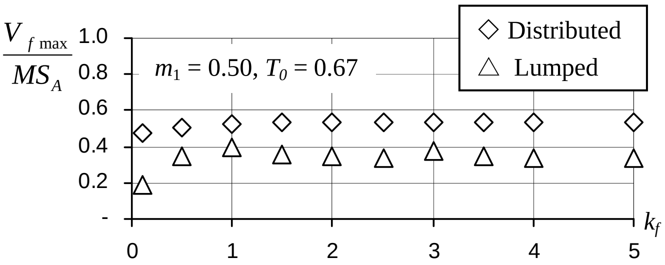

Figure 4. Local shear response comparisons between distributed and lumped mass systems for BCJ

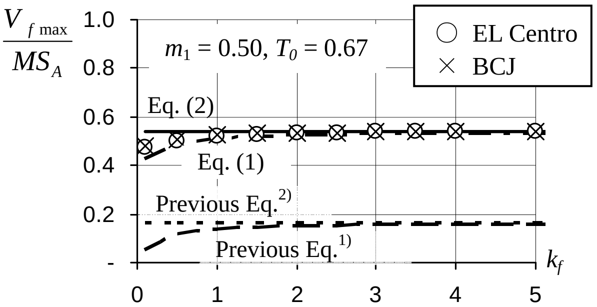

Figure 5. Maximum local shear response comparisons between analytical and predicted values

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