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The resonance responses of steel structure with sliding floor loads

T.Okada
Affect Engineering Design Office, Japan
K.Takanashi
Institute of Industrial Science, University of Tokyo, Japan

ABSTRACT: On numerical analysis of dynamic response of steel structure with sliding heavy floor loads system was executed, it was obtained that the frame response is decreased by choosing friction and stopper gap between sliding loads.

1. INTRODUCTION

The seismic force is usually determined in proportion to the sum of dead and live loads on the floor in the earthquake resistant design procedure. In the case that the equipment is not perfectly fixed on the floor of a building, slipping of the equipment is occurred when the building is subjected to the earthquake motion or some impulse. It is easily expected that the sliding of the heavy equipment may considerably change the response of the building. Moreover, in some cases, the equipment collides against the other load nearby and the movement of loads is restrained by stands provided on the floor. These behaviors will also influence to the response of the structure.
It is most significant on the earthquake remission design to study about what an effect should be considered on the response of a building with sliding load may be.

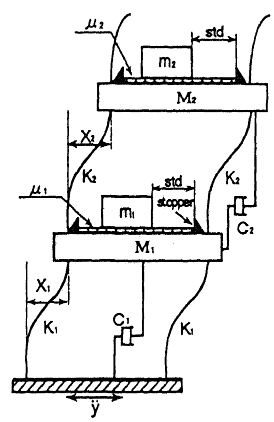


Fig. 1 A frame model for numerical analysis

2.Numerical Analysis Method of sliding loads system

As it is generally difficult to get the response when the complex system is subjected to a random motion like an earthquake wave, the authors have been developed numerical dynamic response analysis method for multi -degree of freedom system (Fig. 1), where the response of shear frame with sliding load (a block) on the each story is assumed. This method based on dynamic defeferential equation is shown as fallows,

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+\{R\}-\{F\} = -[M]\{1\}\ddot{Y} \quad -(1)$$

$$[m]\{\ddot{U}+\ddot{X}\}+\{F\} = -[m]\{1\}\ddot{Y} \quad -(2)$$

where, [M]: mass matrix of a frame
[m]: mass matrix of a block
[C]: dumping coefficient matrix
{R}: restoring vector of a frame in elastic zone {R}=[K]{X}
{F}: friction vector
$\ddot{Y}$: input acceleration

As direct integration, the central deferential method is used in our method. The flow diagram of the analysis method is shown in Fig. 2.
The friction force of i-th floor Fi (i is floor number) is obtained by the below in accordance with the sliding state of a block

I No sliding : $F_i = -m_i(\ddot{X}_i+\ddot{Y}_i)$ -(3)

II Sliding state : $F_i = \mathrm{sgn}(\dot{U})m_i\,\mu g$ -(4)

condition of changing state is

I -> II : $|\ddot{X}_i + \ddot{Y}_i| > \mu g$ -(5)

II -> I : $|\ddot{X}_i + \ddot{Y}_i| <= \mu g$ and $\dot{U}_i = 0$ -(6)

where, μ: friction coefficient (equivalent static and dynamic)
g : acceleration of gravity

It is also considered to analyze about collision of a block against stopper on the assumption that it occurs

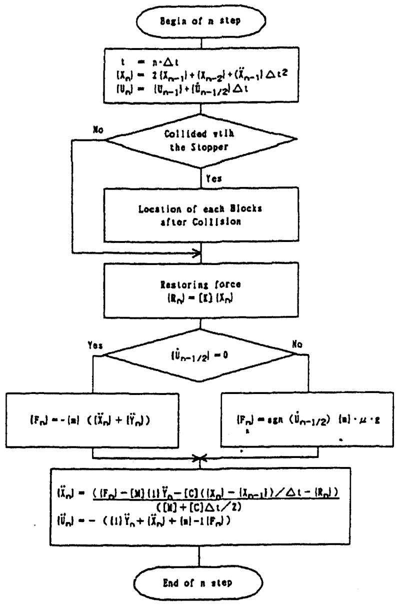


Fig. 2 The flowchart of numerical analysis procedure

in a moment. The friction and restoring forces in an instant of collision are so smaller than the collision force that their influences may be able to be neglected. Concerning the theoretical results of a head-on collision, the applied equation to the frame analysis is as follows

$$\dot{X}_e = \dot{X}_s + \frac{m}{M+m}\dot{U}_s(1+\varepsilon) \qquad \text{-(7)}$$

$$\dot{U}_e = -\varepsilon\dot{U}_s \qquad \text{-(8)}$$

where, $\dot{X}s, \dot{U}s$: velocity of the floor and the block before collision

$\dot{X}e, \dot{U}e$: velocity : of the floor and the block after collision

e : collision coefficient

Our main algorithm of the numerical analysis method for a step calculation is shown as the flowchart in Fig. 2.

1) Using $\{\dot{U}_{n-1/2}\}$ and $\{\ddot{X}_{n-1}\}$ that are obtained from the former step, the response displacement of the frame and the relative response displacement of the block are obtained if it is judged that the collision is occurred based on the relative response displacement of a block.

2) Obtain the restoring force vector $\{R_n\}$ from the response displacement of the frame $\{X_n\}$ and characterized restoring force model of a each story.

3) The relative response acceleration of the frame $\{\ddot{X}_n\}$, the relative response acceleration of a block $\{\ddot{U}_n\}$, and the relative response velocity of a block $\{\dot{U}_{n+1/2}\}$ are calculated.

4) The friction force of a next step is obtained by the relative response velocity of a block.

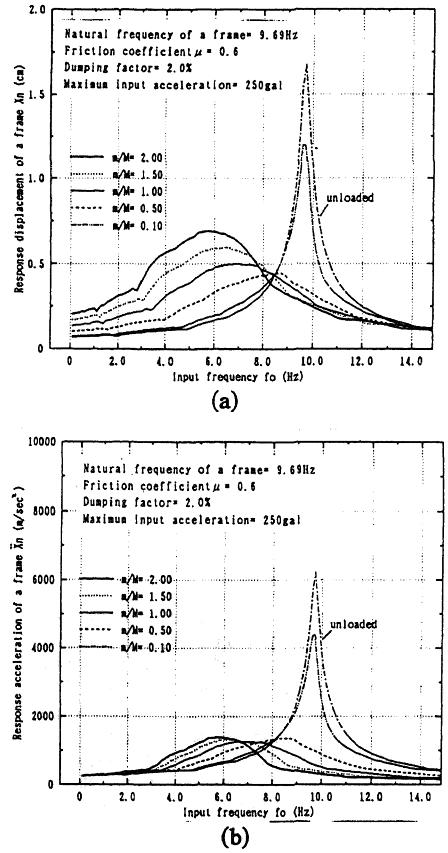


Fig. 3-1 The peak response displacement Xn (a), and acceleration $\ddot{X}n$ (b) to μ=0.6.

Input ground acceleration wave form is the sinusoidal curve, and its maximum amplitude 250cm/sec^2.The time increment in the numerical integration is 1/1000 second.And the program has all variable in double precision.

3. Resolution of a single degree of freedom system

Fig. 3-1 shown the dynamic response spectrum of the oscillator system, where the friction coefficient is fixed 0.6 and ratio of a block mass(m) to a floor mass(M) is parametrically changing.

Increasing the mass ratio m/M, it can be observed that the maximum response displacement decreases shifting the peak position to the low frequency, but increase again around m/M=0.5. The maximum response acceleration spectrum indicates same tendency, but each peak response remains in about 1500 cm/sec^2 for 0.5 to 2.0 of m/M.

In the case of friction coefficient μ of 0.3, and 0.1, the floor response spectra shown in Fig. 3-2, Fig 3-3 respectively. In the figures, the peak values of loaded frame response approach to the peak value of unloaded frame as decreasing friction coefficient. The response for m/M=0.1 is almost equivalent to the response of it.

However, in the case of m/M=2.0, μ=0.1, the floor response decreases about 1/6 of the unloaded frame.

It is apparently effective for the heavy mass system that the slide loading block on the floor allow to slide with less friction in order to decrease response of the frame (Fig. 4).

Though the small peak is observed at 1/3 frequency to the unloading response frequency in μ=0.3 (Fig. 3-2), this phenomenon is more emphasized considerably increasing amplitude of input excitation and decreasing damping coefficient of the frame. As this behavior is also described in the reference[2], these peak are appeared periodically at every frequency cycle $\pi/2n+1$.And the authors also observed this phenomenon at the experiment[1].

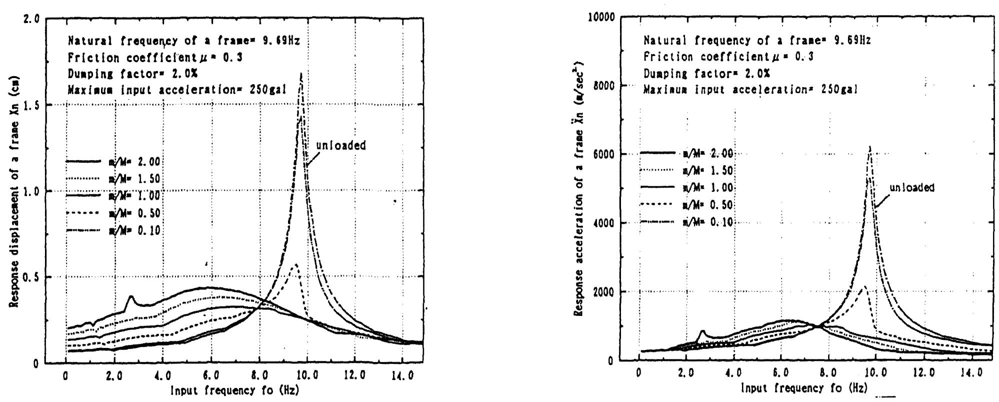
4. The stopper effect

Usually stoppers are installed both sides at a distance from a block on the floor. The authors tried to study about the influence to the floor response spectrum due to stopper effect by changing the stopper gap, mass ratio m/M, and friction coefficient μ. As a result, upon m/M= 2.0, μ=0.1, if the stopper gap ratio (std) is provided to be greater than or equal 50% of the maximum response block displacement without stoppers under the same condition, it can be decreased the frame response displacement by 1/7 of that of a fixed block system regardless of the input frequency. But if the gap is provided to be less than 1/1300, almost same response characteristics as the fixed loading system is obtained. Besides, the response acceleration is almost more than three times as the fixed loading system.

5. Conclusions

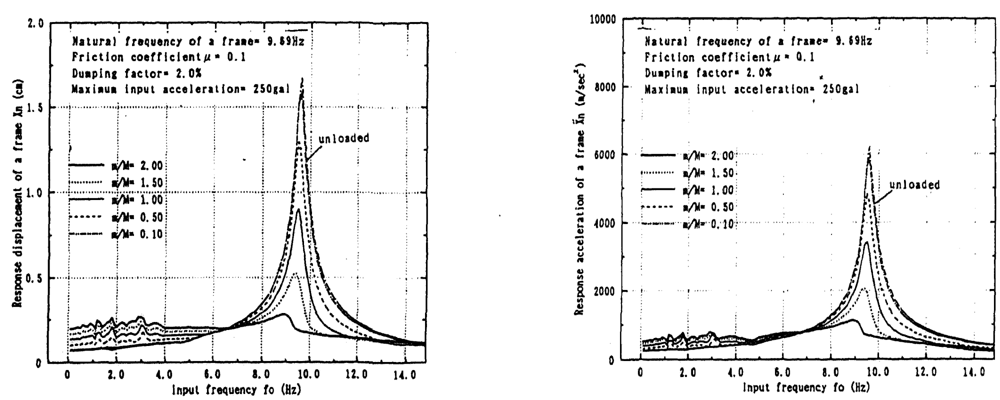
1) The response of oscillator with sliding load system is especially influenced by mass ratio a block to a floor, friction coefficient, gaps of stoppers. If it is the heavy load, the less friction is able to reduce the response displacement and acceleration to the state of unloading system.

2) In order to reduce the response of a frame, the stopper gap from the loading should be required more than 0.1% of the maximum response displacement of a block without stoppers.



(a) (b)

Fig. 3-2 The peak response displacement Xn (a), and acceleration $\ddot{X}n$ (b) to μ=0.3.



(a) (b)

Fig. 3-3 The peak response displacement Xn (a), and acceleration $\ddot{X}n$ (b) to μ=0.1.

ACKNOWLEDGMENT

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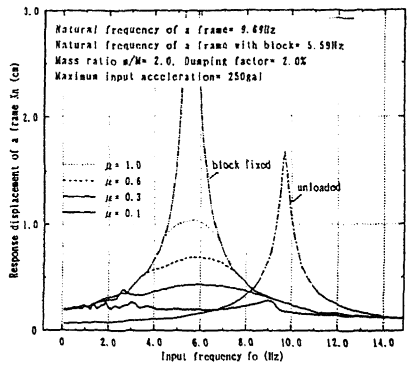
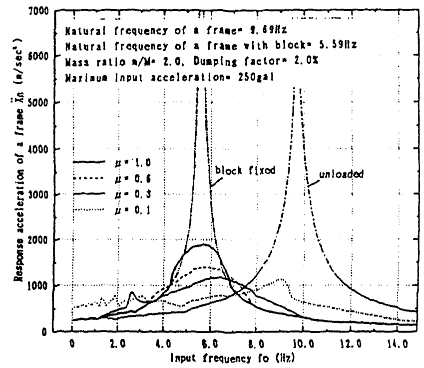
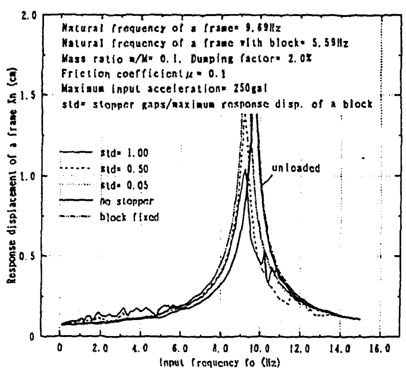


(a)

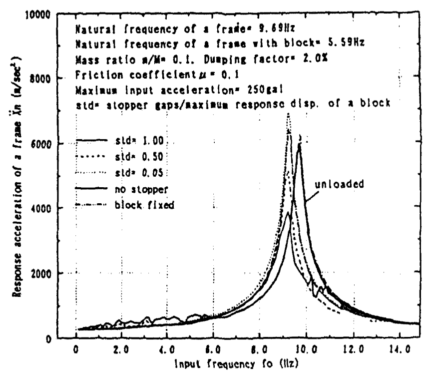


(b)

Fig. 4. The peak response displacement Xn (a), and acceleration $\ddot{X}n$ (b) to m/M=2.0.

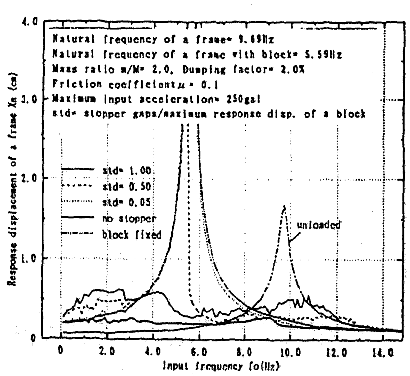


(a)

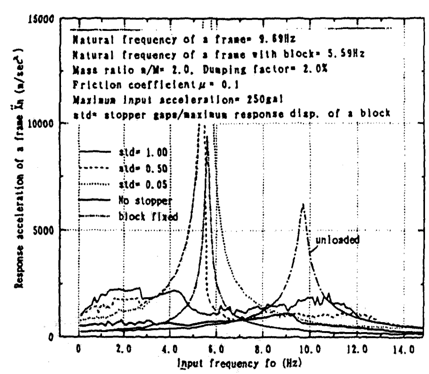


(b)

Fig. 5. The peak response displacement Xn (a), and acceleration $\ddot{X}n$ (b) to m/M=0.1, μ=0.1.



(a)



(b)

Fig. 6. The peak response displacement Xn (a), and acceleration $\ddot{X}n$ (b) to m/M=2.0, μ=0.1.