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Prediction and Reduction of Building Floor Vibration Using Blocking Floor

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Abstract: ***Structural vibrations are harmful to the extended life of any structure. So to mitigate it is of at most importance. Some of the recent research in this field reveals that a simple increase in the thickness of the lowest floor of any building could result in considerable amount of reduction in top floor displacements of the building. Commonly these floors of increased thickness are called Blocking floors and blocking floor method of reducing the vibration is a relatively simple and recent of techniques adopted. A technique which can be classified under system control method, if properly understood will result in a cheap and easy alternative among existing vibration control techniques. The objective here is to find out the effectiveness of blocking floor. Here different steel frame buildings with and without blocking floor are modelled and analysed in programming environment of MATLAB. Response of the building is measured in terms of the impedance of the building and the maximum displacement at different storey levels of the building when subjected to two types of loadings viz. harmonic and earthquake loadings. In general it is observed that with increase in thickness of the blocking floor, the vibration response of the building is being reduced. Other observations made here in this study suggest that the effectiveness of the blocking floor reduces the as the slenderness of the buildings increase and ideal position of the blocking floors in any building will be in lower floors.***

Keywords: Blocking Floor,MATlab,Shear building,Lumped Mass Concept

1. Introduction

Vibration can be defined as repeated movement of a physical object about a fixed point. These can be either periodic or random. Vibrations of structure may be due to natural causes as well as human-activities. The former includes earth quakes, wind, etc and latter includes blasting at mine, quarrying, building basement development, piling, demolition, road and rail traffic etc. Vibrations can cause

- Varying degrees of damage in buildings;
- Disturbance or annoyance to people or, at higher levels, affect a person"s ability to work ;
- Affect vibration-sensitive machinery or equipment.

While designing the majority of buildings and other civil engineering structures, the main actions to consider are those due to gravitational effects. These loads are always present and therefore they must be resisted throughout the entire life of the building. The magnitude of such loads can be quickly determined based on the self weight and the occupancy requirements. Neglecting the variation through time of these loads, a static idealization is considered for the design of the structures. This idealization greatly simplifies the structural design. On the other hand, when dealing with lateral actions, there is a natural trend to manage these forces (such forces which produce vibration) with the same methods used for gravitational loads. For example, wind gusts and earthquakes are often idealized as „equivalent" static loads of certain magnitude that must be resisted by the structure and results have been quite satisfactory. But a dynamic load can have a significantly larger effect than a static load of the same magnitude due to the structure's inability to respond quickly to the loading (by deflecting). Considering the dynamic characteristics of the horizontal loads, significant improvements can be made. In fact in a dynamic point of view, many innovative approaches for structural protection have been proposed. A widely considered strategy consists of incorporating various elements to the structure to mitigate its dynamic response and the branch of Structural Engineering which covers such concepts is called Structural Control.

A blocking floor is a type of thickened slab introduced at the low level flooring. Increasing of thickness of slab reduces the effect vibration along the higher floor. This is the simplest method which needs no expert supervision and can be introduced everywhere. This concept was first introduced at the 2010 Structures Congress, for mitigating train-induced floor vibrations in multi-storey buildings. The main advantage of blocking floor is the avoidance of replace, minimization of maintenance and reduction of cost etc. In this study, the buildings are modelled as lumped mass systems and analyzed, both in programming environment of MATLAB. A parametric study is carried out understand

- The effectiveness of blocking floor in buildings of varying numbers of storeys.
- The effectiveness of blocking floor with varying thickness of the same.
- The effectiveness of blocking floor placed at different storey level of a given building.

Building performance is analysed by studying the response of building using New-mark beta algorithm, when subjected to harmonic and earthquake loading. Response parameters include the impedance of the building and maximum displacement at different storey levels of building.

2. Scope of the Study

Excessive floor vibration has become a greater problem as new rhythmic activities, such as aerobics, and long-span floor structures have become more common. This update with most advanced and cheapest method i.e., by providing blocking floor in the lowest floor gives an options for avoiding the excessive vibrations through design, or in the case of existing buildings, reducing or eliminating it through alterations.

3. Objectives of the Study

Vibration is up-and-down motion forces applied directly to the floor by people or machinery, or by vibration transmitted through building columns, from other floors or from the ground. This vibration affects the life of the structure very seriously. Structural engineers have been trying out different innovative approaches by introducing new materials and new techniques that mitigate vibration effectively. In this project, focus is on the effectiveness in reducing the floor vibrations due to ground excitation by simply increasing the thickness of the lowest floor which is commonly called a Blocking floor.

4. Dynamics

Structural Dynamics is a subset of structural analysis which covers the behavior of structures subjected to dynamic loading and more importantly analysis which considers the dynamic response of the structure. Dynamic loads include people, wind, waves, traffic, earthquakes, and blasts. Any structure can be subject to dynamic loading. Dynamic analysis can be used to find dynamic displacements, time history and for modal analysis. Even in structural dynamics, it is not always possible to obtain rigorous mathematical solutions for engineering problems. In fact, analytical solutions can be obtained only for certain simplified situations. For problems involving complex material properties, loading and boundary conditions, the engineer introduces assumptions and idealizations deemed necessary to make the problem mathematically manageable, but still capable of providing sufficiently approximate solutions and satisfactory results from the point of view of safety and economy. The link between the real physical system and the mathematical feasible solution is provided by the mathematical model which is symbolic designation for substitute idealized system including all the assumptions on the physical problem.

A shear building may be as a structure in which there is no rotaiton of a horizontal section at the level of the level of the foorls. In the respect, the deflected buildign will have many of the features of a cantilver beam that is deflected by shear forces only; hence, the name shear building. To accomplish such deflection in a building, we must assume that:

- The total mass of the structure is concentrated at the levels of the floors
- The girders on the floors are infinitely rigid as compared to the column
- The deformation of the structure is independent of the axial forces present in the columns.

A. Lumped Mass System

A multi-storeyed moment resistant frame is modelled as a string with distributed floor masses at different levels, joined by mass less connectors having different storey stiffness values. Figure 1 show a lumped-mass building model, with floor mass as mi, stiffness as ki and floor displacement as xi.

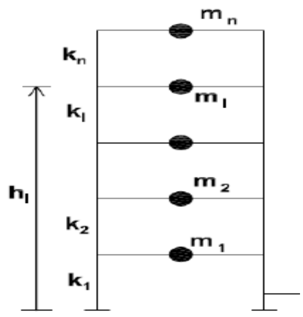

Figure 1: Lumped-mass model

$m_1, m_2, m_3 \ldots m_n$ are the lumped masses, $k_1, k_2, k_3 \ldots k_n$ are the stiffness. h_i is the height in which the mi lumped mass situated.

We have the equation of motion as:

$$\begin{bmatrix} m_{11} & m_{12} & \cdots \\ m_{21} & m_{22} & \cdots \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{Bmatrix} \ddot{z}_1 \\ \ddot{z}_2 \\ \vdots \end{Bmatrix} + \begin{bmatrix} c_{11} & c_{12} & \cdots \\ c_{21} & c_{22} & \cdots \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{Bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \vdots \end{Bmatrix} +$$

$$\begin{bmatrix} k_{11} & k_{12} & \cdots \\ k_{21} & k_{22} & \cdots \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{Bmatrix} z_1 \\ z_2 \\ \vdots \end{Bmatrix} = (2.1)$$

And it can be simplified as:

$$[M]\{\ddot{z}\} + [C]\{\dot{z}\} + [K]\{z\} = \{\bar{F}\} \ (2.3)$$

$$M\{z\}_{n \ 1} + C\{\dot{z}\}_{n \ 1} + K\{z\}_{n \ 1} = -M(z_0)\omega^2 \ (2.4)$$

This equation can be solved by two methods

- Solution by the normal mode summation method.
- Direct solution of the global equations of motion.

Direct Integration method

In the direct integration the equation (2.3) are integrated using a numerical step by step procedure. The term “direct integration” means that prior to the numerical integration no transformation of the equation into a different form is carried out. In essence direct numerical integration is based on two ideas. First, instead of trying to satisfy (2.3) at any time it aims to satisfy (2.3) only at discrete time intervals Δt apart. This means that static equilibrium, the effect of inertia and damping forces, is sought at discrete time points within the interval of solution. Therefore it appears that all solution techniques employed in static analysis can probably also be used effectively in direct integration. Secondly, the variation of displacements, velocities and accelerations within each time interval Δt is assumed. The form of assumption affects the accuracy, stability and cost of the solution procedure. The solution for the shear building model can be obtained using several numerical integration methods. Some of the direct solution methods are listed below:

- Central difference method
- Houbolt method
- New-mark method

5. Blocking Floor

The concept of using Blocking Floor to mitigate vibrations in the upper floors is new to Structural Engineering and vibration control. The idea of blocking floors was first introduced at the 2010 Structures Congress, for mitigating train-induced floor vibrations in multi-storey buildings. It involves the increase in the thickness of the floors to block the vibration from transmission to upper floor thus the name. This approach to vibration mitigation is attractive to designers and owners because it can be achieved with standard construction elements and without jeopardizing the building"s lateral resistance to wind loads. Since it involves modification in the system properties, it can be grouped under the category of the System Modification Method of vibration control. Mass Addition applies Newton"s 2nd Law, F=Ma which implies that if the mass of a system is increased while the force input remains constant, acceleration (vibration response) will decrease. The influence of a thicker lower floor in reducing the vibrations at the upper floors was first observed by some of the Professors of the Tufts University, who later put forward the conference paper on blocking floors. The TD Bank north Garden, a 9-storey steel framed sports arena had thicker and heavier floor slab and a deep girder on the third floor. It was found and confirmed that the increased floor thickness of the third floor reduced the train induced vibration in the higher floors to a great extent.In short, these studies showed that vibration transmitted through building columns to the upper floors can be mitigated by considerably increasing the thickness of a lower floor, which is termed the blocking floor. Since the blocking floor involves the modification of the thickness of one of the storey it can be classified under system modification of the vibration control.

6. Numerical Analysis

a) Matlab

Numerical analysis of effectiveness of blocking floor in mitigating harmonic and earthquake (random) vibration is done with the help of MATLAB. A computer program was developed in MATLAB for performing dynamic analysis on multi-storey buildings. A brief explanation is given below.

- Firstly, create an EXCEL sheet to give the input data (length, breadth, thickness, density of plate, column and blocking floor, type of loading, amplitude, frequency etc.).(Table 7.1)
- In MATHLAB, create the programme for mass(M), stiffness(K), and damping(C).
- New-mark Beta Method: Once the K, M and C vectors are formulated, the New-mark method is

Incorporated for finding the displacement matrix at discrete intervals of time (Δt=.001s). The constants for the New-mark method (a_0, a_1, a_2,a_3,a_4,a_5, a_6, a_7) are calculated with δ=0.5, α=1/6 and Δt. The initial displacement (U_0), the initial acceleration ($\ddot{U}_0$)and initial velocity ($\dot{U}_0$) are initialized with null vectors and iterated with an increment in time interval (Δt=.001s) in subsequent iterations with loading vector given as $z_0\omega^2\sin(\omega t)$. After the iterations $U, \dot{U}$ and $\ddot{U}$ for different degrees of freedom at different instants of time are obtained and plotted.

Table 1: Input Excel Sheet

Number of Stories	12	Nil
Length of Plate (lp)	0.25	m
Breadth of Plate (bp)	0.2	m
Thickness of Plate(tp)	0.01	m
Density of plate (Steel) (dp)	7850	kg/m3
Blocking Floor Position (bfn)	2	Nil
Blocking Floor Thickness(bft)	0.01	m
Height of the Column	3	m
Area of C/S	5.15E-05	m2
Second Moment of Inertia of the Column	1.89E-11	m4
Density of Column (Steel)	7850	kg/m3
Modulus of Elasticity of Column (Steel)	2.00E+11	N/m2
Damping matrix formulation	1	1-Rayleigh, 2-Caughey
Damping Ratio	0.05	
Type of loading	1	1-Harmonic, 2-Earthquake
Amplitude	0.01	m
Frequency	5	Hz
Time increment	0.01	Second
Total time	30	Second

7. Results

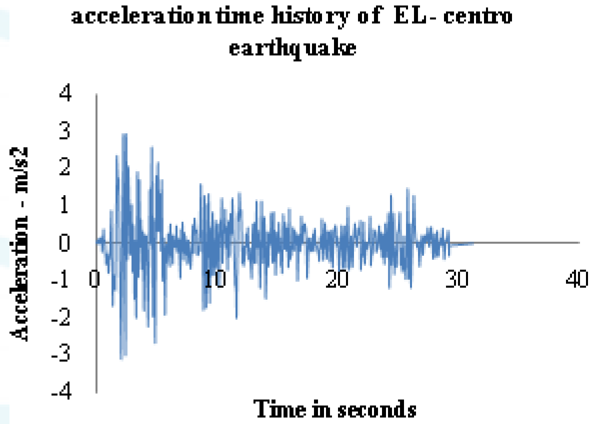

Figure 2: Acceleration Time History of EL-Centro Earthquake

a) Earthquake Loading

1) Effect of Variation of Thickness of floor

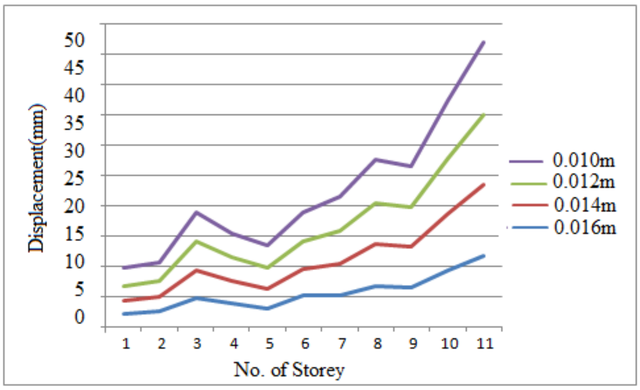

Figure 3: Effect of variation of thickness of blocking floor

When considering the variation of thickness (0.01m, 0.012m, 0.014, 0.016m) of blocking floor following variations are found:

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The blocking floor effect is found to be less effective in the case of earthquake loading. There is no common character to generalize the effect of earthquake loading. It is due to the zig-zag variation of force.

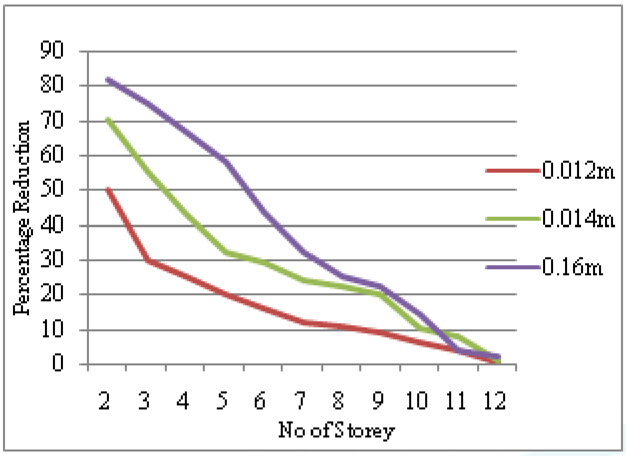


Figure 4: Percentage Reductions in Displacement

When considering the effect of percentage reduction of displacement for the various thickness at ground floor, percentage reduction is maximum for 0.016m blocking floor (fig 4). Also it observed that the percentage reduction of displacement reduces when height increases.

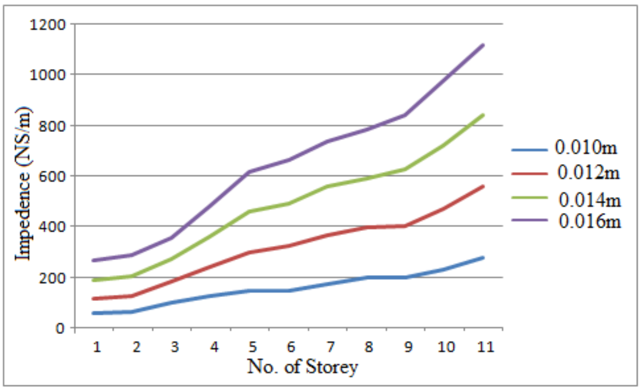


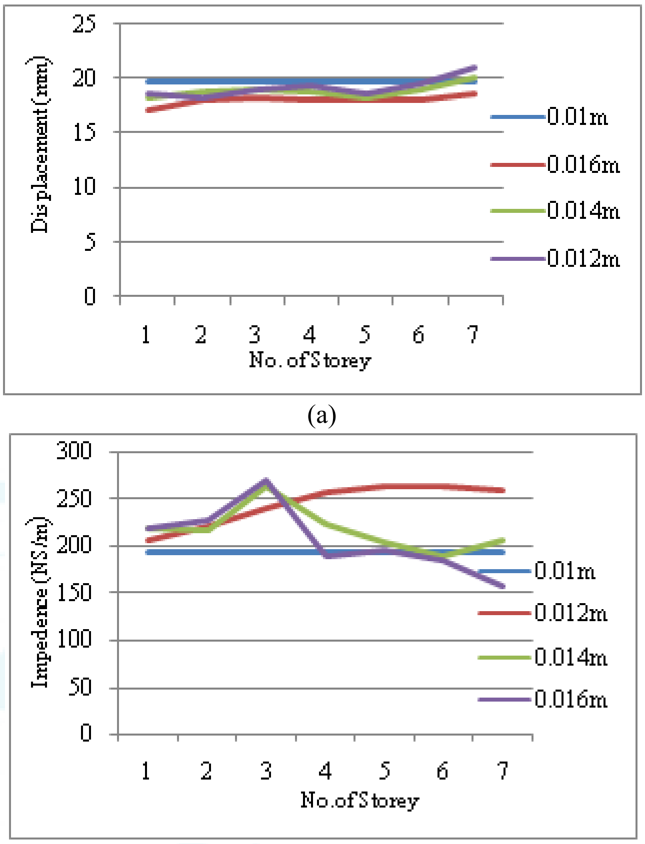
Figure 5: Effect of Variation of Thickness of Blocking floor

In the case of impedence value, maximum impedence observed for the thickness of 0.016m (figure 5.5, f). Also the impedence change observed maximum for 6-8 storey building.

2) Effect of Variation in Position of Blocking Floor

Here the position of 0.01m, 0.012m, 0.014m, 0.016m thickened floor changes from 2-7 storey. The observations are:

Displacement variation is less effective in the case of earthquake loading. Maximum reduction of displacement is observed when the blocking floor placed at ground floor. After that, the value of displacement increases and become change vigorously when the position of blocking floor at 7 storey. Figure indicates the variation of impedence value with respect to the position of blocking floor. There will not found any common profile for the variation because earthquake loading is a random loading. Overall observation gives the idea that the value of impedence increases along the thickness increases.



(a)

(b)

Figure 6: Effect of Change in Blocking floor Position

b) Harmonic Loading

1) Effect of variation of thickness of Blocking floor

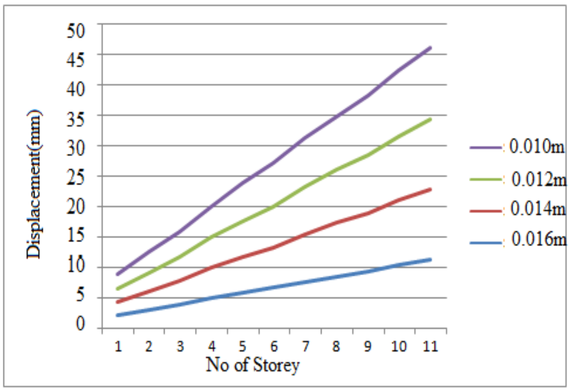


Figure 7: Effect of variation of thickness of Blocking floor

Here found that the displacement decreases with increases the thickness (figure 5.9). It found that there is a linear variation of displacement. When considering the percentage reduction the effect reduces for increase the stiffness (figure 5.8).

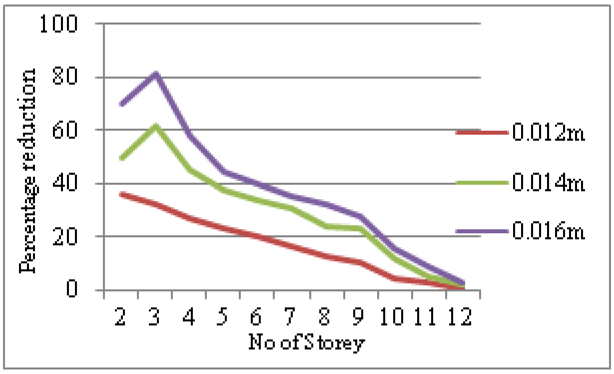


Figure 8: Percentage Reduction in Displacement

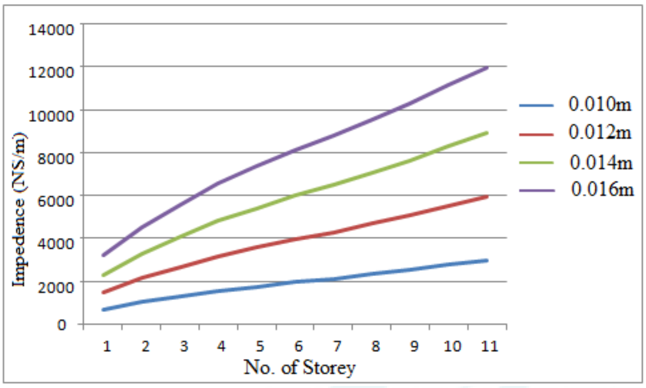
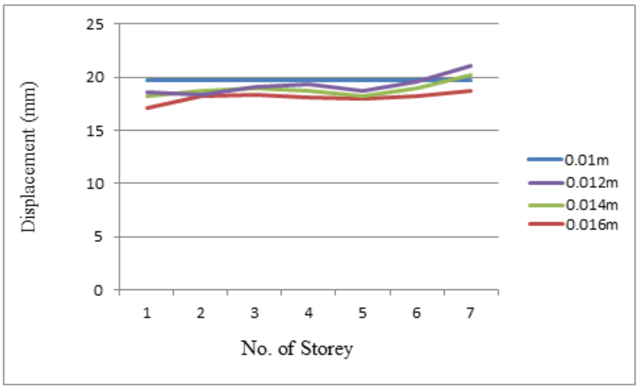


Figure 9: Effect of Variation of Thickness of Blocking floor

When the case considering for impedence, the value of impedence increases when the thickness increases (figure 5.9). But the effect is less along the slenderness ratio increases.

c) Effect of Variation in Position of Blocking Floor

Here considering a 7 storey building. The effect of change the position of blocking floor made considerable increase in displacement. It concluded that when blocking floor position changes to upper storey, there is no effect of blocking floor in displacement. And the graph shown below:



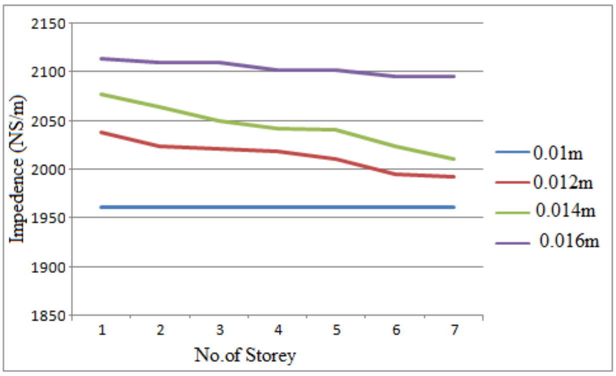


Figure 10: Effect of Change in Blocking floor Position

But considering the impedence the value decreases when the position of blocking floor changes from 1-7 storey. The variation showing graph is given above.

8. Conclusions

From the study, it concluded that:

When loading applied (both harmonic and earthquake loading) it saw that the structure behaves like a cantilever beam that is displacement maximum at top storey and minimum at bottom storey.

- When the thickness changes to 0.01m to 0.016m the displacement value reduces for top storey.
- When the position of blocking floor changes the effect of blocking floor neglected when it reach top floor.
- Displacement and impedence are affect inversely. That is displacement reduces when impedence increases.
- When thickness of blocking floor increases, the impedences of top storey increase and reduce displacement.
- When considering the percentage reduction in displacement top storey effect is less.
- When considering the percentage reduction in impedence top storey effect is less.

This study is limited for a simple hypothetical model. In future the work can be developed as follows:

- The effect of change in bay of a building can be analysed
- Concrete or any other material can be used as blocking floor

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