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Dynamic response of ground floor slab due to friedlander local load

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Abstract. Blast load is one of the common phenomena that may heavily damage a building. As a dynamic force, blast loads require further studies. The effect of blast loads on ground floor slab is studied in this paper. Dynamic responses are affected by many factors, such as shear modulus, soil stiffness modulus, and slab thickness. In this study, blast load is modeled in accordance to Friedlander local load, including its negative phase. Although being smaller in amplitude, negative phase causes larger deflections as shown in some previous studies. The Cubic Negative Phase equation used in modeling the Friedlander local load is recommended by Naval Facilities Engineering Command Design Manual 2.08. A number of variations on loading positions, slab thickness, and damping ratios are made to observe the change in its dynamic responses. The result of the study shows that the addition of slab thickness and damping ratio helps reduce the absolute maximum deflection, while the further the local load is located, the larger deflections are caused.

1. Introduction

A blast load is characterized by a rapid release of energy [1]. This study aims to learn the effect of Friedlander local load on a ground floor slab. Friedlander local load represents a blast load as a dynamic force as seen in Figure 1. This model of blast loading is recommended by Naval Facilities Engineering Command Design Manual 2.08 [2], and has been widely used in previous researches, including the recent study of blast wave induced brain injury [3].

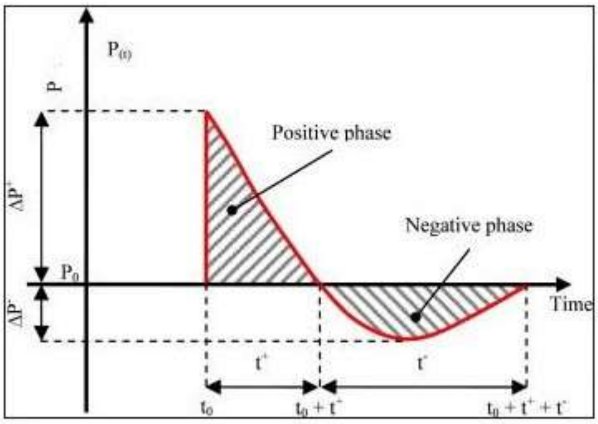

Figure 1. Friedlander local load graph [4]

There are some models proposed by researchers to represent Friedlander local load. Cubic Negative Phase is considered the most accurate model [5]. The equation of this load, according to Cubic Negative Phase is as follows:

$$p_r(t) = \begin{cases} p_{r,max}\left(1-\frac{t}{t_d}\right)e^{-a_1\frac{t}{t_d}}, t \le t_d \\ -p_{r,min}\left(\frac{6.75(t-t_d)}{t_d^-}\right)\left(1-\frac{(t-t_d)}{t_d^-}\right)^2, t_d < t \le t_d + t_d^- \end{cases} \quad (1)$$

2. Methods

2.1. General Analysis

Pasternak elastic foundation models the soil underneath a slab as a layer of spring and a shear layer, as shown in Figure 2.

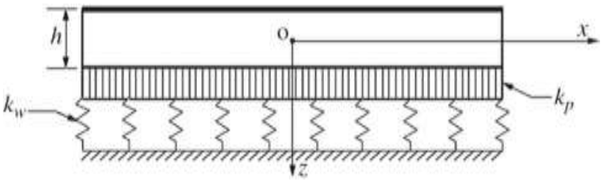

Figure 2. Pasternak elastic foundation model [6]

The motion equation of a dynamically loaded orthotropic plate with Pasternak elastic foundation support can be expressed as:

$$D_x\left(\frac{\partial^4 w(x,y,t)}{\partial x^4}\right) + 2B\left(\frac{\partial^4 w(x,y,t)}{\partial x^2 \partial y^2}\right) + D_y\left(\frac{\partial^4 w(x,y,t)}{\partial y^4}\right) + \rho h\frac{\partial^2 w(x,y,t)}{\partial t^2} + \xi h\frac{\partial w(x,y,t)}{\partial t} + kfw(x,y,t) - Gs\left(\frac{\partial^2 w(x,y,t)}{\partial x^2} + \frac{\partial^2 w(x,y,t)}{\partial y^2}\right) = p_z(x,y,t) \quad (2)$$

2.2. Homogeneous Solution

The equation as shown in (2) can be solved by using separation of variables method, thus making two separate equations, which are spatial differential equation W(x,y) and temporal differential equation T(t) [7]. Therefore, homogeneous solution can be expressed as:

$$w_{pq}(x,y,t) = W(x,y).T(t) = X_{pq}(x).Y_{pq}(y).T(t) = X.Y.T \quad (3)$$

where:
W(x,y): spatial function
X(x): position in x-axis
Y(y): position in y-axis
T(t): temporal function

2.3. Particular Solution

Particular solution can be obtained by using separation of variables method. Coefficients of homogeneous solution are expanded according to excitation forces that have not been included in homogeneous solution. The particular solution can be expressed as:

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$$w_p = w_{pq}(x,y,t) = \sum_{p=1}^{\infty} \sum_{q=1}^{\infty} X_{pq}(x) Y_{pq}(y) T_{pq}(t) \tag{4}$$

2.4. Dynamic Force Function

The function used in this study is Cubic Negative Phase. The constants of the function are used according to a past study [8]. The dynamic force function can be expressed as follows:

$$P(t) = \begin{cases} 28906\left(1 - \frac{t}{0{,}0018}\right) e^{-0{,}35\frac{t}{0{,}0018}}, t \leq 0{,}0018\ s \\ -7226{,}5\left(\frac{6{,}75\,(t-0{,}0018)}{0{,}0036}\right)\left(1 - \frac{(t-0{,}0018)}{0{,}0036}\right)^2, 0{,}0018 < t \leq 0{,}0054 \end{cases} \tag{5}$$

2.5. Properties of Slab

Three types of slab with different thickness and damping ratio are modeled in this study. The properties were made according to the commonly used properties of ground floor slab, with 5 meter length, 3.5 meter breadth, 5% damping ratio, and 20 cm thickness. To study the effect of damping ratio to the dynamic response, a similar slab with 10% damping ratio is modeled, and to study the effect of thickness to dynamic response, the thickness of the slab is increased to 22 cm.

2.6. Dynamic Response Analysis Method

Modified Bolotin Method is used in this study. This method is known to produce a more accurate solution on higher vibration modes [9].

2.7. Boundary Conditions and Edge Restraints

In order to evaluate the dynamic stiffness matrix, the kinematic and static boundary conditions must be imposed [10]. The boundary conditions imposed in this study represent semirigid restraints on every edge. This is based on a standpoint that simply supported slab is an oversimplification.

3. Results and Discussion

3.1. The Effect of Friedlander Load Position to Maximum Dynamic Deflection

The effect of different loading points to maximum dynamic deflection in positive phase of the load can be observed in Figure 3. X-axis shows the position of loading, and y-axis shows the maximum deflection in meter.

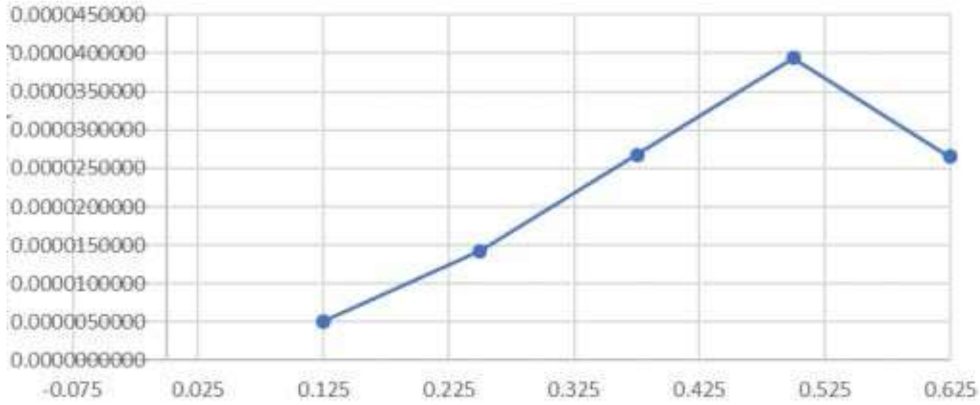

Figure 3. Load position effect in positive phase

The effect of different loading points to maximum dynamic deflection in negative phase of the load can be observed in Figure 4. X-axis shows the position of loading, and y-axis shows the maximum deflection in meter.

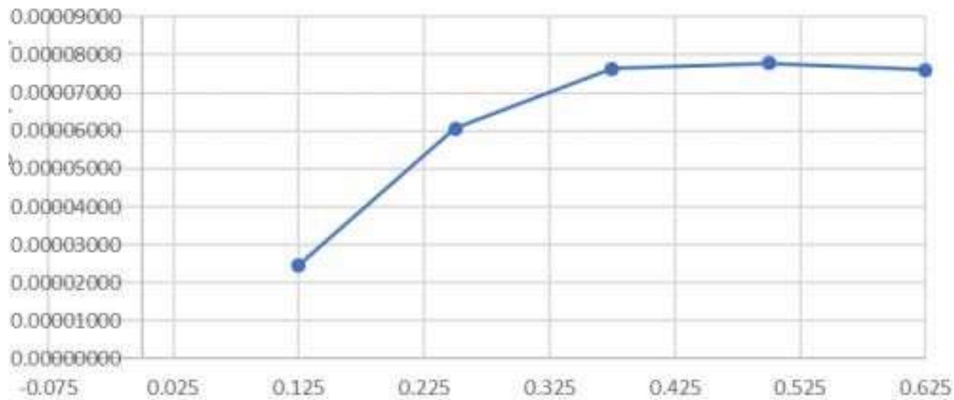

Figure 4. Load position effect in negative phase

According to the results shown in Figure 3 and Figure 4, the further the blast load is located from the support, the larger deflection can be observed. These results also show that although having a smaller amplitude, negative phase causes larger deflection than the positive phase.

3.2. The Effect of Damping Ratio to Maximum Dynamic Deflection

Figure 5 shows the effect of higher damping ratio to the maximum dynamic deflection of a slab. X-axis shows time in second, and y-axis shows deflection in meter. The increase of 5% in damping ratio caused 35.63% lower maximum deflection.

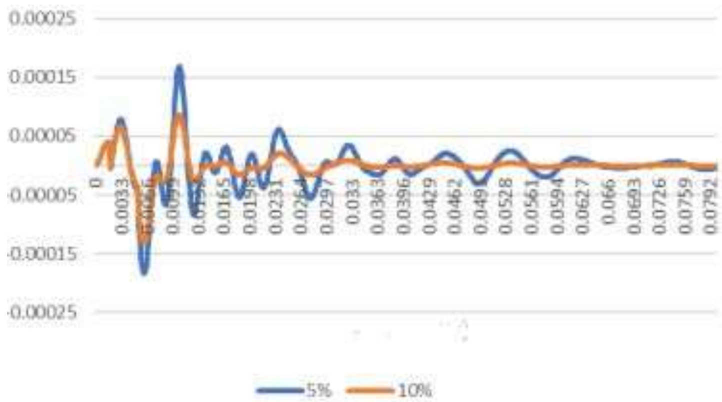

Figure 5. Time history of slabs with different damping ratios

3.3. The Effect of Slab Thickness to Maximum Dynamic Deflection

Figure 6 shows the effect of higher slab thickness to the maximum dynamic deflection of a slab. X-axis shows time in second, and y-axis shows deflection in meter. The increase of 2 cm in damping ratio caused 2.35% lower maximum deflection.

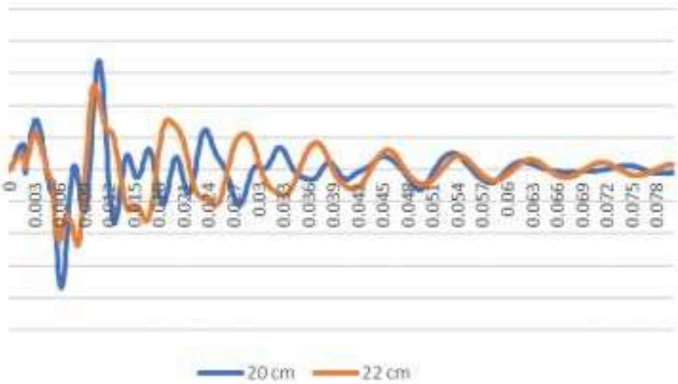

Figure 6. Time history of slabs with different thickness

4. Conclusion

A research has been conducted to study the effect of Friedlander local load to dynamic responses of ground floor slab. It can be concluded that the negative phase causes larger deflection despite its lower amplitude, making it not conservative to be neglected. The increase of damping ratio and slab thickness can help minimize the maximum deflection of the slab.

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