International Journal of Application on Sciences, Technology and Engineering
(IJASTE)
Volume 1, Issue 1, 2023.ISSN:2987-2499

PARAMETRIC ANALYSIS OF BLAST LOAD EFFECT ON DIAPHRAGM WALL IN BASEMENT

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Submitted: November-December 2022, Revised: January 2023, Accepted: February 23, 2023

Abstract. There are various kinds of loads acting on the basement structure of a building, blast load for an example. In this study, the effect of variation of the structural and soil parameter values on the response of the basement structure due to blast load will be analyzed. Thus, it can be seen the influence of the tested parameters. The deformation of the diaphragm wall will be the focus of this research. This research will be using Midas GTS NX program in modeling the basement structure of the building and the surrounding soil using the finite element method. The analyzed basement structure consists of flat slabs, diaphragm wall, king posts, raft, and pile foundation. The analyzed blast load is a surface blast load of 40000 liters of gasoline that occurs at a distance of 20m from the building and will be analyzed using the time history method. The analysis was carried out on 12 parameters: the void ratio of soil, the density of soil, cohesion, undrained shear strength, elasticity modulus of soil, poisson ratio of soil, porosity, structural damping ratio, damping ratio of soil, shear angle of soil, diaphragm wall's thickness, and concrete's quality of the diaphragm wall. From the results of the analysis, it is found that the parameters that affect the deformation of the diaphragm wall are the modulus of elasticity of the soil, density of soil, the poisson ratio of the soil, diaphragm wall's thickness, and the concrete's quality of the diaphragm wall. The soil modulus of elasticity has greatest influence on deformation changes, which is 282.27%, while concrete compressive strength of diaphragm wall has smallest influence, which is 0.87%.

INTRODUCTION

In planning a basement structure in a building, one of the important things to consider is the behavior or response of the structure. The structural response can occur due to both static and dynamic loads or time-dependent loads. The dynamic analysis of a structure is very crucial considering that a structure can vibrate either due to external factors or due to internal factors such as the characteristics of the material or materials that make up the structure. An example of dynamic loads that can occur in a basement is blast load. Blast load on building structures can occur due to several events, such as terrorist bomb attacks, gas station explosions, explosions due to mining activities, and many more. After World War I and II, people began to understand the importance of protecting buildings from the effects of explosions to save human lives. One of the most recent explosion events in Indonesia was the explosion of the PT Pertamina (Persero) RU VI Balongan Indramayu oil tank which occurred on March 29, 2021.

Even though it is located underground, the basement cannot be separated from the possibility of being damaged due to blast load. Therefore, it is necessary to analyze the response of the basement structure. The basement structure itself consists of retaining walls, flat slabs, king posts, a raft, and bored piles. The response of the structure due to external loads is influenced by many parameters, both the soil and structure parameters. By testing the variation of the value of these parameters due to blast load, it can be seen the effect of these various parameters on the response of the structure. The structural response that is focused in this research is the deformation of the diaphragm wall in the basement structure. This research will be using Midas GTS NX finite element program.

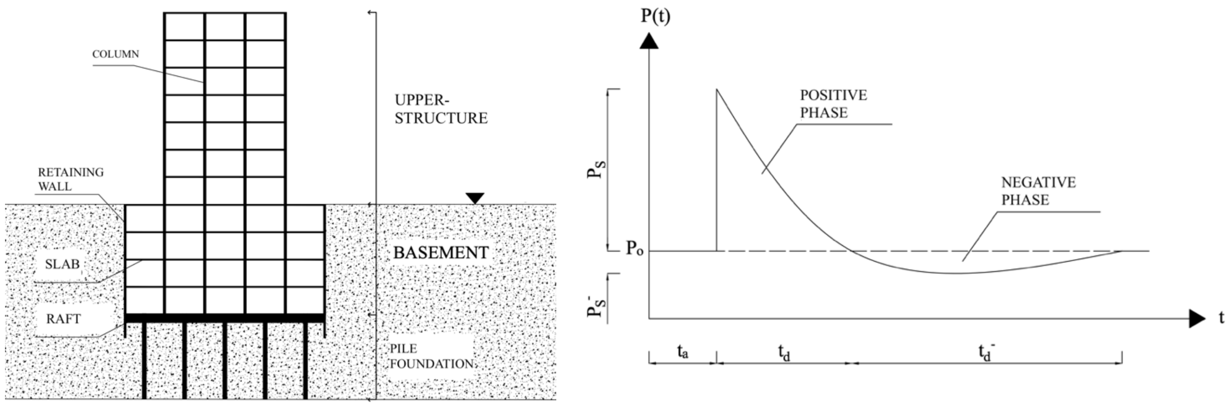
https://doi.org/10.24912/ijaste.v1.i1.132-139

LITERATURE REVIEW

Basement and Diaphragm Wall

The basement is part of the structural component of the building which is located underground as shown in Fig.1(a). The basement is usually constructed for a high-rise building. Construction of a basement will need the excavation of the ground. Basements are usually used for upper structure's balance, vehicle parking space, management room, supporting building utilities such as panel room placement, reservoirs, and other needs. [4]

The diaphragm wall is an artificial membrane with a certain thickness and a certain depth. A diaphragm wall is a retaining wall that is installed as a further development system of the secant pile and contiguous pile system. The use of a diaphragm wall system is very economical because there are many beneficial factors when compared to a continuous retaining wall system. [4]



(a) (b)

FIGURE 1. (a) The basement's structure [1], (b) The phase of blast load [1]

Blast Load

An explosion is a sudden process of increasing pressure and releasing destructive energy due to chemical reactions and generally releases gases and hot temperatures. Explosions can be very destructive if they are close to a building because the pressure generated is enormous. An explosion that produces a shock wave is categorized as a detonation. In an explosion at ground level, some of the energy is released as heat energy, while some are released into the air as an air blast and into the ground as a shock wave. Describing the size of the explosion can use units equivalent to TNT. TNT (Trinitrotoluene) is a yellow and odorless man-made solid that has a high explosive power. [1]

The characteristic of the detonation of an explosion begins with an instant increase in atmospheric pressure to its peak pressure, which is known as the peak incident pressure. After the shockwave spreads out, its pressure decreases until it reaches the initial pressure around it. Theoretically, the pressure decreases exponentially. The phase from which the pressure rises to falls to atmospheric pressure is called the positive phase. After the pressure reaches the ambient pressure, the pressure changes to the suction pressure which is called the negative phase as shown in Fig. 1(b). The negative phase has a longer duration than the positive phase. [1]

The pressure equation resulting from the explosion can be formulated as follows:

$$P(t) = P_o - P_S^- \left(\frac{t}{t_d^-}\right)\left(1-\frac{t}{t_d^-}\right) e^{-4\frac{t}{t_d^-}} \quad (1)$$

Description:

P_o	: ambient pressure (MPa)	t_d	: duration of pressure in the positive phase (s)
P_s	: peak pressure (MPa)	t_d^-	: duration of pressure in negative phase (s)
t	: time after the incoming wave(s)		

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RESEARCH METHODS

The procedures carried out in this research are descripted as follows:

1. The initial stage of this research begins with collecting soil and building layout and data from the project that will be used in the research.
2. The next stage is to conduct a literature study on the basement structure, diaphragm wall, blast loads, and the characteristics of the soil and structure parameters.
3. Then processing the soil data that has been obtained using typical values and correlations of soil parameters from various sources to produce soil design parameters.
4. The next step is modeling the soil and basement structure. The modeling was carried out using the Midas GTS NX program.
5. Then input the material data and values of tested parameters in the Midas GTS NX program.
6. After the modeling, an analysis was performed using the time-history method for blast load.
7. The next stage is to analyze the results of deformation that occurs in the diaphragm wall.
8. After that change the value of the tested parameters, then analyze again so that new analysis results are obtained. Perform these steps repeatedly until the results of the analysis of all the tested parameters are obtained.
9. The results of the analysis obtained are then compared so that it can be seen the effect of various parameters tested on the deformation of the diaphragm wall.
10. The last stage is to formulate the conclusions from the results of this study and suggestions for future research.

Soil Data

Soil data in this study were obtained from laboratory test data and data from SPT (Standard Penetration Test). From these data, the value of the soil design parameter is obtained from the average value of the soil parameter at each certain depth. Soil parameters that are not available in laboratory test data and SPT data are obtained by using soil parameter correlations. The soil parameter values used for soil modeling in this study are shown in Table 1.

TABLE 1. Soil design parameters

Layer	Soil Layer Elevation		Type	Consistency	N-SPT	γ_{sat} (kN/m^3)	γ_{wet} (kN/m^3)	e_0	φ' (°)
	Top (m)	Bottom (m)							
1	0	17	*Clay*	*Medium*	6	14	13	2.3	10
2	17	32	*Clay*	*Stiff*	14	16	16	1.8	7
3	32	40	*Clay*	*Very Stiff*	20	16	16	1.5	6
4	40	52	*Clay*	*Very Stiff*	26	17	17	1.1	6
5	52	68	*Clay*	*Very Stiff*	28	17	17	1.1	4

TABLE 1. Soil design parameters (cont.)

Layer	s_u (kPa)	c (kPa)	OCR	E (MPa)	E_{50} (kPa)	E_{oed} (kPa)	E_{urref} (kPa)	k (m/s)	μ	Ψ (°)	n
1	30	10	2.0	4	2,200	2,200	6,600	10^{-8}	0.35	0	0.70
2	70	20	1.0	8	4,400	4,400	13,200	10^{-8}	0.30	0	0.64
3	100	65	1.0	10	5,500	5,500	16,500	10^{-9}	0.40	0	0.60
4	130	90	1.0	12	6,600	6,600	19,800	10^{-9}	0.40	0	0.52
5	140	100	0.5	16	8,800	8,800	26,400	10^{-9}	0.40	0	0.52

with γ_{sat} = saturated soil density, γ_{wet} = wet soil density, e_0 = soil void ratio, φ = angle of shear resistance, s_u = undrained shear strength, c = cohesion, OCR = over-consolidated ratio, E = soil modulus of elasticity, E_{50} = soil secant modulus, E_{oed} = soil oedometer modulus, E_{urref} = soil unloading/reloading modulus, k = soil permeability, μ = soil poisson ratio, Ψ = dilatancy angle, n = soil porosity

Basement's Property

The basement structure analyzed is a 5-story basement with 3m height between floors. The basement slab system is a flat slab with a thickness of 0.25m and the retaining wall analyzed is a diaphragm wall type. The drop panel size

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used is 1.8m x 1.8m with a thickness of 100mm. The foundation system in the basement is a raft-pile foundation with a raft thickness of 2m and the foundation used is a circular bored pile foundation with a diameter of 1.8m. King post used is an H-steel profile with 406 x 403 x 26.5 x 42.9 dimensions.

Blast Load

The blast load analyzed is a surface explosion which is assumed to be from a gas tank explosion from a gas station opposite the building. The gas tank is assumed to have a volume of 40,000 liters. The stand-off distance is assumed to be 20m away. The basement is assumed to be unaffected by the fragmentation effects of the explosion. The time history of the explosion of 40,000 liters of gasoline is shown in Fig. 2.

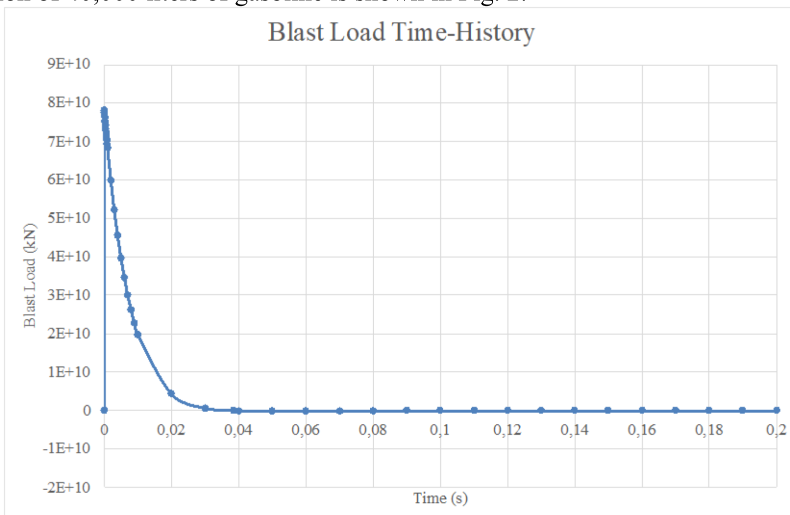
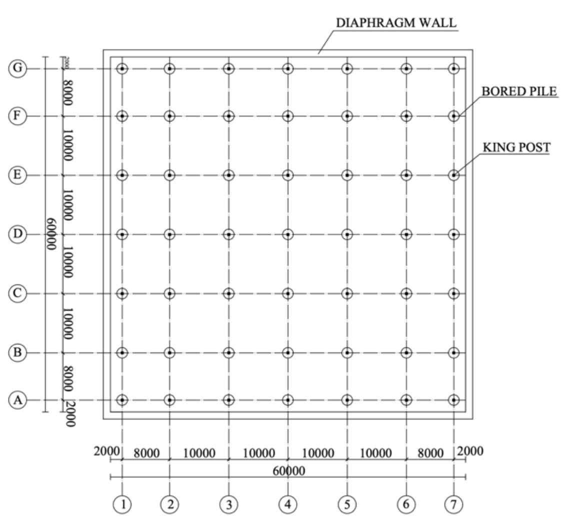
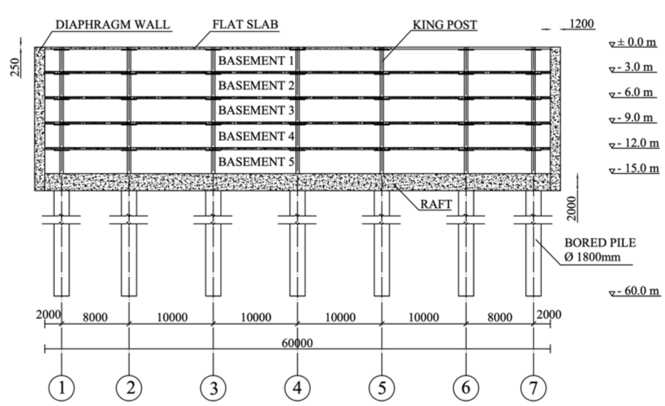


FIGURE 2. Blast load time-history

Basement Model

The layout and section of the analyzed basement are shown in Fig. 3(a) and Fig. 3(b).





(a) (b)

FIGURE 3. (a) The analyzed basement layout, (b) section A-A

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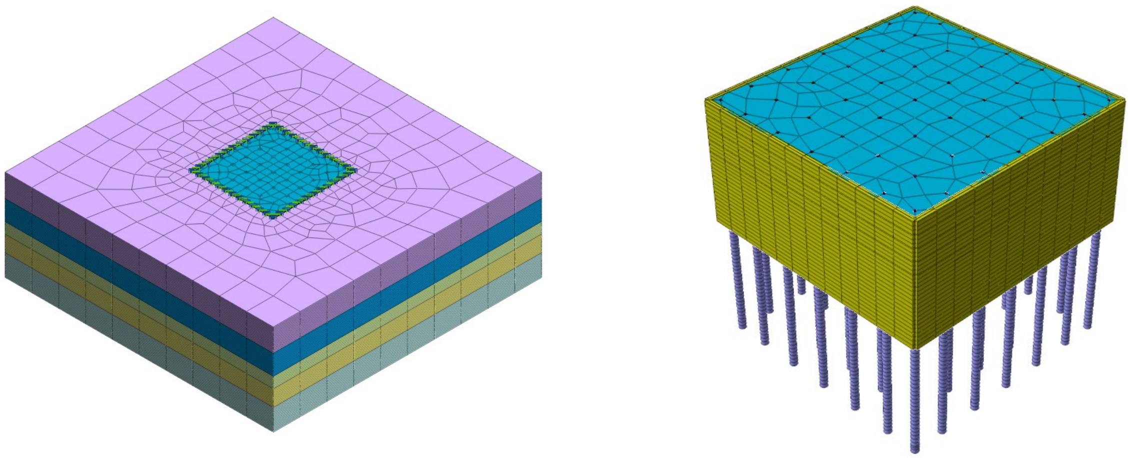
Finite Element Modelling

The finite element program used in this study is Midas GTS NX. The soil material is modeled as modified mohr-coulomb and the structural material is modeled as elastic. Diaphragm walls are modeled as shell elements (2D), while plates, rafts, and soil layers are modeled as solid elements (3D). For bored pile and king post modeled as beam (1D). The models are shown in Fig. 4(a) to Fig. 4(b).



(a) (b)

FIGURE 4. Modeling on the finite element program (a) soil layers modeling, (b) basement structures modelling

Tested Parameters

In testing the soil parameters, the soil parameters are changed only in layer 1 and 2 because these layers are in contact with the diaphragm wall in the basement. Soil layers are considered isotropic. Each parameter is tested with 5 (five) different value variations so that there are 5 cases for each parameter. The tested parameters are tabulated in Table 2.

TABLE 2. Tested parameters

Case	c (kPa)	φ (°)	γ (kN/m^3)	e_0	n	μ	E (MPa)	s_u (kPa)	ζ_{soil}	$\zeta_{structure}$	t (m)	f_c' (MPa)
1	5	5	10	0.5	0.3	0.25	4	50	0.01	0.01	0.5	20
2	15	10	15	1.0	0.4	0.30	7	100	0.03	0.03	1.0	25
3	30	20	20	1.5	0.5	0.35	10	150	0.05	0.05	1.5	30
4	45	30	25	2.0	0.6	0.40	15	200	0.07	0.07	2.0	35
5	60	40	30	2.5	0.7	0.45	20	300	0.1	0.1	2.5	40

with c = cohesion, φ = angle of shear resistance, γ = soil density, e_0 = soil void ratio, n = soil porosity, μ = soil poisson ratio, E = soil modulus of elasticity, s_u = undrained shear strength, ζ_{soil} = soil damping ratio, $\zeta_{structure}$ = structure damping ratio, t = diaphragm wall's thickness, dan f_c' = diaphragm wall's concrete quality.

RESULTS AND DISCUSSION

The results of parametric analysis on the deformation of the diaphragm wall will be shown in graphical form for direct comparison. The results of the analysis are given in Fig. 5(a) to Fig. 5(f).

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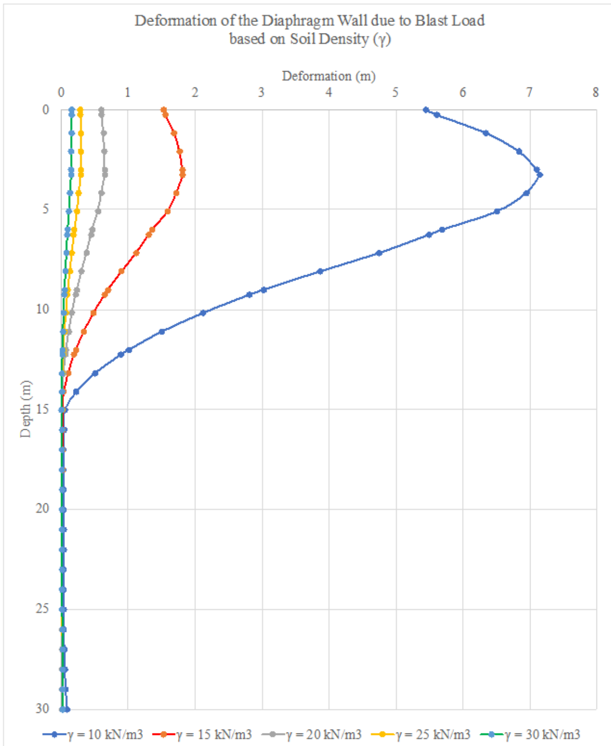
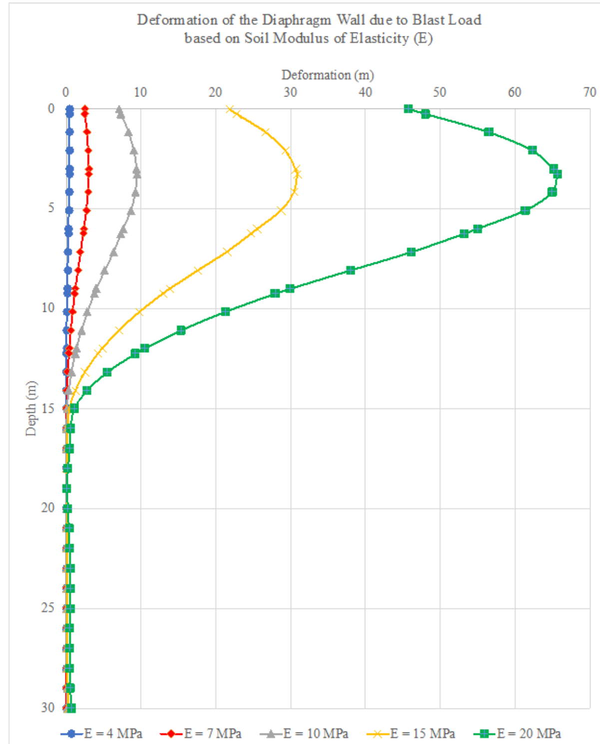


(a)



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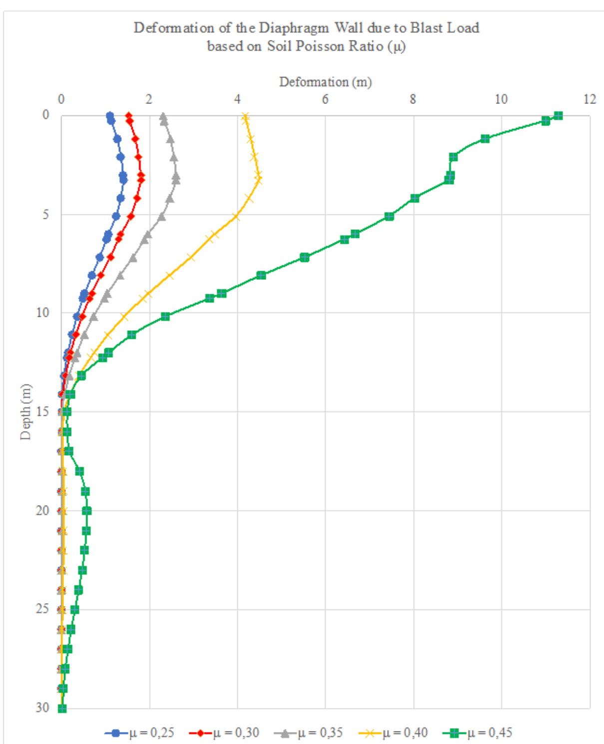
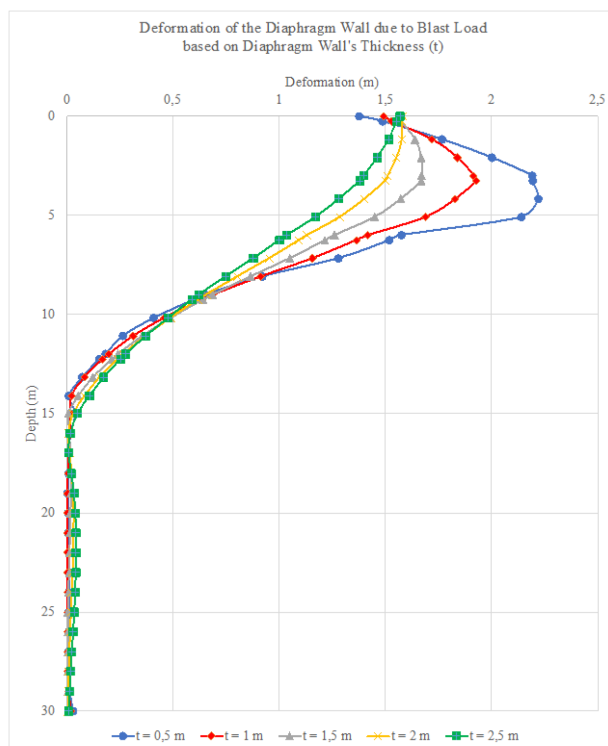


(c)



(d)

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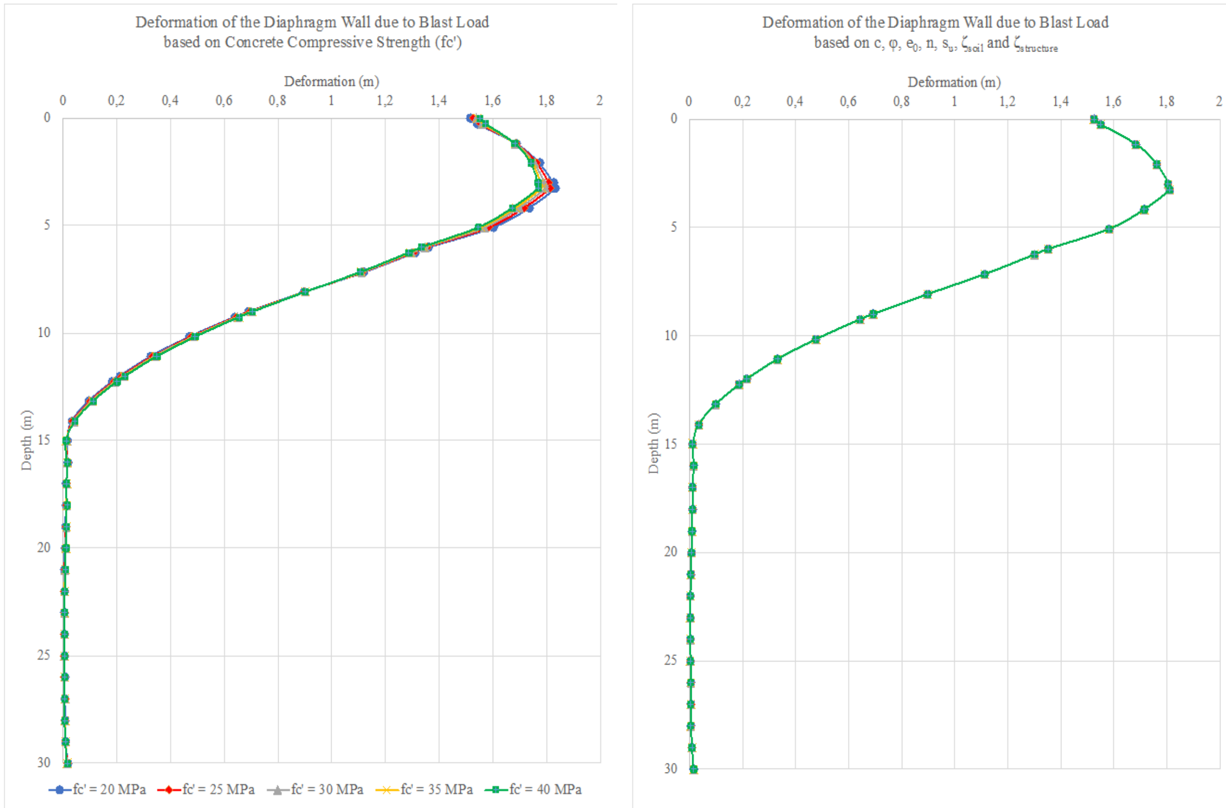

(e) (f)

FIGURE 5. Deformation of the diaphragm wall due to blast load based on (a) soil density, (b) soil modulus of elasticity, (c) soil poisson ratio, (d) diaphragm wall's thickness, (e). concrete compressive strength, (f) cohesion, angle of shear resistance, soil void ratio, soil porosity, undrained shear strength, damping ratio of soil and damping ratio of structure

Results of the analysis using the Midas GTS NX program were then compared. The results compared are the maximum deformation changes of the diaphragm wall due to blast load. The positive sign (+) on the percentage change in deformation indicates a directly proportional effect, it is an increase in the deformation of the diaphragm wall when the value of the test parameter is increased. While the negative sign (-) on the average percentage change in deformation indicates an inversely proportional effect, it is a decrease in the deformation of the diaphragm wall when the value of the test parameter is increased. The change in deformation for each increase in the parameter values tested is given in Table 3.

TABLE 3. Maximum Deformation Change of Diaphragm Wall

Case	c	φ	γ	e_0	n	μ	E	s_u	ζ_{soil}	$\zeta_{structure}$	t	f_c'
1 → 2	0	0	-74.65	0	0	28.33	577.86	0	0	0	-13.15	-1.09
2 → 3	0	0	-64.25	0	0	43.82	211.72	0	0	0	-13.33	-0.94
3 → 4	0	0	-55.79	0	0	71.91	226.94	0	0	0	-5.21	-0.78
4 → 5	0	0	-46.23	0	0	152.01	112.54	0	0	0	-0.95	-0.67
Average	0	0	-60.23	0	0	74.02	282.27	0	0	0	-8.16	-0.87

CONCLUSION

Based on the results of the analysis that has been obtained, several conclusions can be drawn as follows:

1. Blast loads are dynamic loads that can affect the design of the diaphragm wall of the basement.

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2. Parameters that affect the deformation of the diaphragm wall due to blast loads are the soil modulus of elasticity (E), the soil poisson ratio (μ), and the soil density (γ), the diaphragm wall thickness (t), and the diaphragm wall's concrete compressive strength (fc').
3. The soil modulus of elasticity (E) has the biggest effect on the average deformation change among all parameters, which is 282.27%.
4. The diaphragm wall's concrete compressive strength (fc') has the smallest effect on the average deformation change among the all parameters, which is -0.87%.
5. The soil poisson ratio (μ) affects the average deformation changes by -74.02%, the soil density (γ) affects the average deformation changes by -60.23%, and the diaphragm wall thickness (t) affects the average deformation changes by -8.16%.
6. To reduce the deformation of the diaphragm wall, the value of the soil density (γ), the diaphragm wall thickness (t), and the diaphragm wall's concrete compressive strength (fc') need to be increased. On the other hand, the value of the soil modulus of elasticity (E) and the soil poisson ratio (μ) need to be reduced.

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