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Designing a Single-Floor Structure for the Control Room of a Petroleum Refinery and Assessing the Resistance of Such a Structure against Gas Explosion Load

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***Abstract*—**Explosion occurs due to sudden release of energy. Common examples of explosion include chemical, atomic, heat, and pressure tank (due to ignition) explosions. Petroleum, gas, and petrochemical industries operations are threatened by natural risks and processes. Fires and explosions are the greatest process risks which cause financial damages.

This study aims at designing a single-floor structure for the control room of a petroleum refinery to be resistant against gas explosion loads, and the information related to the structure specifications have been provided regarding the fact that the structure is made on the ground's surface. In this research, the lateral stiffness of single pile is calculated by SPPLN.FOR computer program, and its value for 13624 KN/m single pile has been assessed. The analysis used due to the loading conditions, is dynamic nonlinear analysis with direct integration method**.**

***Keywords*—**Gas Explosion Load, Petroleum Refinery, Single-Floor Structure

I. Introduction

IN this study, a single-floor structure constructed on pile has been modeled in the form of a two-degree freedom system with elasto-plastic behavior and analyzed under explosion load, and direct integration based on Wilson method has been used in its analysis. Of course, it is necessary to mention that analysis has been also accomplished for an ideal model of one-degree freedom. Parametric studies have been accomplished for two frames with 6 meter and 9 meters width with different heights. Dynamic analysis of foundation system includes calculation of the lateral rise of the system under effect of dynamic load. For this purpose, computer programs written with FORTRAN programming language are used in this study. The first program is GS.FOR used to calculate the stiffness of pile group. This program is based upon Novak and Sharnobay method the fundamentals of which will be discussed in the coming chapters. The second program is SPPLN.FOR program used to calculate the lateral rise of the single pile under the effect of lateral load. In the above-mentioned program the pile immersing in soil has been modeled on an elastic bed (Winkler method) and would be analyzed based on the limited element method. Many studies have been performed in relation with explosion and its effects [1]-[5].

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II. Design Specifications

The information related to structure specifications taking into account the fact that the structure is located on the ground's surface, Fig.1 shows a surface effective against explosion with an area of 6 x 6 m^2 and concrete resistance of 20 Mpa, and the consumed reinforcements of 415 Mpa.

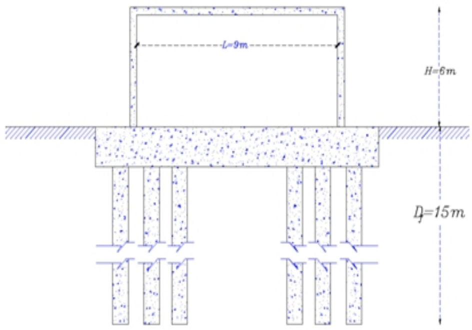

Fig. 1 frame of a building constructed on pile

III. Specifications of Foundation & Soil

Use either Length of each pile is 15m and its diameter is 0.45m. Regarding the fact that the soil bed is sandy, modulus of the subgrade reaction is considered to be K_h = 5000 KN/m^3 according to geotechnical studies. Besides, capacity of piles is 30 KN, the soil shear modulus is G = 15 N/mm^2, Poisson's ratio is $\nu = 0.2$, modulus of elasticity is $E_{dyn} = 30000 N/mm^2$, and the safety factor for horizontal and vertical loading of each pile is 2.5.

IV. Specifications of the Explosion Load

Explosion is made equivalent by a triangular load according to Fig. 2 with extraordinary peak pressure of P_{so} and time of t_d.

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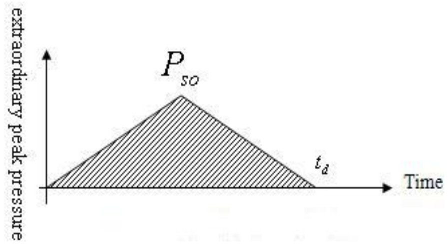

Fig. 2 Explosion Loading pressure

To start the study, the back pressure is calculated according to the flash peak pressure, and dimensions of walls and thickness of the ceiling is estimated. Regarding the type of explosive material and its cost, the following specifications have been offered for the present example:
Flash peak pressure: P_{so} = 70 KN/m^2
Time of explosion: t_d = 30 milli sec

V. Structural Frame Layout

To start the work, it is supposed that the structure period is 0.15 Sec; as a result, the ratio of explosion time to the structure period is equal to: $\tau = \frac{t_d}{T} = \frac{0.03}{0.15} = 0.2$ according to the data.

The flash and exceeding pressure is 70 KN/m^2, and regarding the fact that the flash peak pressure comes onto the ceiling, the flash static flux on the ceiling is equal to: $R_r = \frac{70}{3.744} = 180.7 KN/m^2$, and the flexural frame system design load is determined based on the final load and through lateral mechanism. The load spread on the frame is equal to $47.6 \times 6 = 285.6 KN/m$ per meter.

VI. Design & Dynamic Analysis

The structure distributed mass is considered to be equivalent by virtue of a concentrated mass to the supposition that the strain energy is produced by zero-mass springs. Similarly, distributed loads are also made equivalent by virtue of some concentrated loads incurred onto concentrated mass. Therefore, equivalent system includes several concentrated mass interconnected by zero-mass springs and are under effect of a concentrated load which changes by time. This concentrated system of mass and spring is called structure dynamic system. Transformation of an optional structure into an equivalent system calls for dynamic similarity rule which says that the accomplished work, the strain energy, and the kinetic energy of the equivalent system get equal to the main structure accordingly.

Every optional structure (a single-floor or a multi-floor structure) the parts of which include the beam or column, should become equivalent by a dynamic equivalent system for the purpose of dynamic analysis.

According to U.S Army report TM5- 1300 : structure dynamic analysis means to determine the rise of the structure parts under flash load made by Newton equation. Acceleration, speed, and rise changing with time are determinable through solving the equation of system balance [6]. (In general issues of design, the time-load diagram is known, but structural parameters (dimensions of beam and columns) are unknown); therefore, they have to be supposed. By solving the balance equation, the system's peak rise is obtained and is to be compared with the permissible value. If proper structural specifications are selected, the sections are proper for design, otherwise, new sections are to be selected, and the problem should be solved again. The process of structural design should be performed as trial and error till the favorable section is obtained.

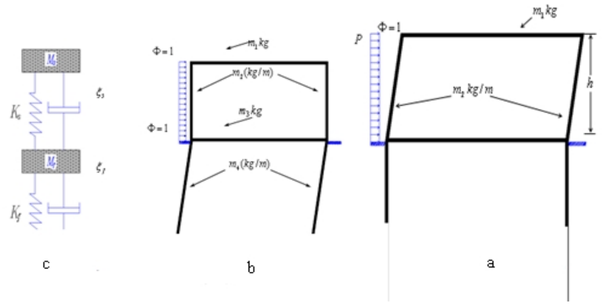

Fig. 3
(a): transformation of the plastic frame with rigid foundation under the effect of lateral load
(b) : transformation of the plastic foundation with rigid frame under the effect of lateral load
(c) : the ideal model of system with two degree of freedom under the effect of lateral load

VII. Result

After calculating the rate of the rise induced by the frame, the equivalent stiffness is calculated. In this stage, SAP2000 program is used, and the horizontal rise of the beam is estimated to be Δ = 3.185 mm. Furthermore, the frame lateral flexural stiffness is $K = 62800 \frac{KN}{m}$. the mechanism ruling over the column is the lateral mechanism which means that the columns fracture like the beam on both hinge ends under the effect of lateral load. The total lateral load incurred into the structure by the explosion force is equal to F = 1200 KN. In this research, the lateral stiffness of the single pile is calculated by SPPLN.FOR computer program, and its value for the single pile of the present case is 13624 KN/m.

The diagram of the effect of frame stiffness on transformation of the foundation, and the effect of foundation stiffness on transformation of superstructure has been obtained based on values, and also the effect of the frame resisting force on transformation of foundation and the effect of foundations resisting force on transformation of the frame is given later.

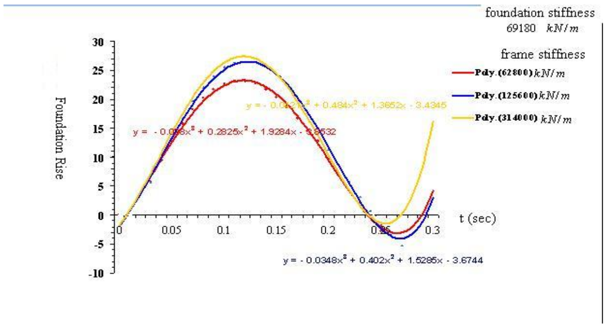

Fig. 4 the effect of frame stiffness on foundation transformation

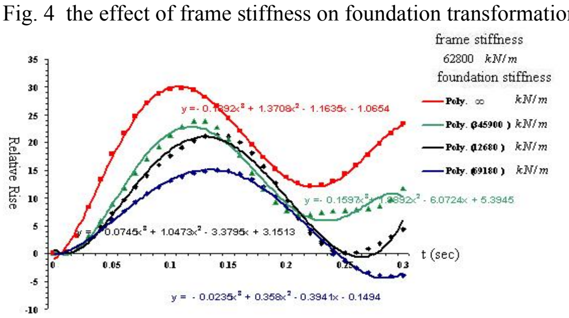

Fig. 5 the effect of foundation stiffness on superstructure transformation

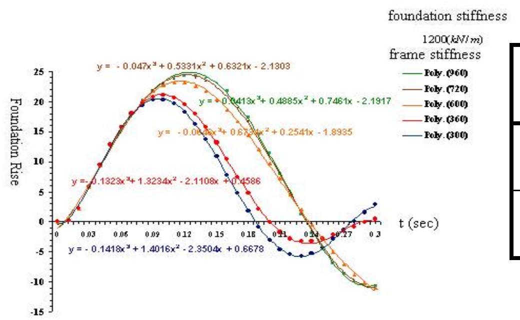

Fig. 6 the effect of the frame resisting force on foundation transformation

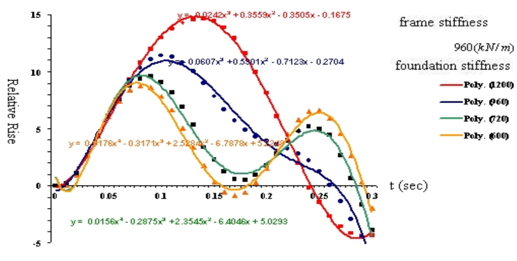

Fig. 7 the effect of the foundation resisting force on frame (superstructure) transformation

After calculation of the system period regarding the fact that all the parameters required for dynamic analysis are prepared, by the use of SAP2000 program and direct integration based on Newmark method, the results are presented in the following table in 3 parts:

TABLE I
RESULTS OF ONE-DEGREE FREEDOM SYSTEM ANALYSIS (PLASTIC FRAME, RIGID FOUNDATION)

Structure System	*System Reaction (KN)*	*Failure Point Rise X_e (mm)*	*Maximum Rise X_m (mm)*	*Plasticity Factor X_m/X_e*	*t_{max} sec*
frame	600	9.55	29.538	3.09	0.096

TABLE II
RESULTS OF ONE-DEGREE FREEDOM SYSTEM ANALYSIS (PLASTIC FOUNDATION, RIGID FRAME)

Structure System	System Reaction (KN)	Failure Point Rise X_e (mm)	Maximum Rise X_m (mm)	Plasticity Factor X_m/X_e	t_{max} sec
foundation	1200	17.35	27.865	1.61	0.108

TABLE III
RESULTS OF TWO-DEGREE FREEDOM SYSTEM ANALYSIS (FRAME AND FOUNDATION ARE BOTH PLASTIC)

Structure System	System Reaction (KN)	Failure Point Rise X_e (mm)	Maximum Rise X_m (mm)	Relative Rise X_r (mm)	Plasticity Factor X_m/X_e	t_{max} sec
frame	600	9.55	37.342	14.457	1.514	0.118
foundation	1200	17.35	23.068	23.046	1.33	0.11

VIII. CONCLUSION

In this study entitled " Designing a Single-Floor Structure for the Control Room of a Petroleum Refinery & Assessing the Resistance of Such a Structure against Gas Explosion Load" it was observed that increment of foundation stiffness increases the frame plasticity. In larger buildings, through extreme stiffness increment the frame elasticity becomes doubled, and by increasing the frame (superstructure) stiffness the foundation plasticity reaches to 1.75 from 1.33, that in case of larger buildings the increment is about 0.33%. Therefore, superstructure stiffness has not a great effect on foundation transformation.

Furthermore, the plasticity and rise factor of foundation does not change that much in the two systems with one and two degrees of freedom, and great changes occurs in frame (superstructure) rise for one and two-degree freedom systems. In the first structure, the rise of the two-degree freedom system is relatively twice as much as that of the one-degree freedom system, and in case of the second structure, also, the changes are significant but not equal to those of the first structure. Therefore, in more accurate methods, two-degree freedom system represents more economical results. By decreasing the system stiffness, the rate of plasticity changes in one-degree and two-degree freedom systems decreases.

It is suggested that the dynamic analysis accomplished in this study is appropriate for single-floor buildings. To expand the present method, regarding the fact that recognition of failure mechanism gets complicated, one may write a program to determine the ruling mechanism and use it in analysis.

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