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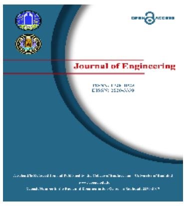

Civil and Architectural Engineering

Effect of Embedment on Generated Bending Moment in Raft Foundation under Seismic Load

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ABSTRACT

This research shows the experimental results of the bending moment in a flexible and rigid raft foundation rested on dense sandy soil with different embedded depth throughout 24 tests. A physical model of dimensions (200mm*200mm) and (320) mm in height was constructed with raft foundation of (10) mm thickness for flexible raft and (23) mm for rigid raft made of reinforced concrete. To imitate the seismic excitation shaking table skill was applied, the shaker was adjusted to three frequencies equal to (1Hz,2Hz, and 3Hz) and displacement magnitude of (13) mm, the foundation was located at four different embedment depths (0,0.25B = 50mm,0.5B = 100mm, and B = 200mm), where B is the raft width. Generally, the maximum bending moment decreased with increasing the embedment depth from zero to B, by (75%,41%, and 43%) for the flexible raft under (1, 2 and 3) Hz respectively, for the rigid raft the maximum bending moment decreased by (62%, and 37%) under (1and 2) Hz respectively, for 3Hz excitation frequency, the direction of behavior wasn't the same for the case of the rigid raft foundation as the maximum bending moment increased with increasing the embedment depth from zero to (0.25B,0.5B and B) by (142% , 268% and 5%) compared with the surface raft foundation.

Keywords: raft foundation, bending moment, embedment depth, shaking table, sandy soil

تاثير عمق الدفن للأساس الحصيري على عزم الانحناء المتولد تحت تاثير الاحمال الزلزالية

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الخلاصة

هذا البحث يسجل النتائج العملية من خلال اربع فحوصات لدراسة استجابة الاساس الحصيري الموضوع بأعماق مختلفة في تربة رملية كثيفة . تم صنع موديل لبناية بمقياس صغير بأبعاد (200ملم ×200 ملم) وارتفاع (320) ملم كما تم استخدام اساس حصيري من الكونكريت المسلح بسمك (10) ملم للاساس المرن و(23) ملم للاساس الجاسئ. لتمثيل التأثير الزلزالي ، استخدمت تقنية المنضدة الهزازة لتمثيل الهزة الارضية ، وقد تم ضبط المنضدة لأعطاء ثلاثة

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ترددات مختلفه (1و2و3) هرتز وازاحة مقدارها (13) ملم ، تم وضع الاساس في اربع اعماق مختلفة (0 ، 0.25 B=50 ملم ، B 0.5 =100 ملم ، B = 200 ملم) ، حيث تمثل (B) عرض الاساس الحصيري . عموما، ان عزم الانحناء الاعظم يقل بزياده عمق دفن الاساس من صفر الى (B) بنسبه(75٪،41٪،43٪) للاساس المرن للترددات (1و2و3) هرتزعلى التوالي ،اما للاساس الجاسئ فان عزم الانحناء الاعظم قل بنسبة(62٪،37٪) للترددات (1و2) هرتزعلى التوالي.لوحظ ان الاساس الجاسئ تحت تاثير (3) هرتز سلك سلوك مختلف حيث ان عزم الانحناء الاعظم ازداد بزيادة عمق دفن الاساس من صفر الى(0.25 B ، 0.5 B ، B) بنسبه (142٪،268٪،5٪) على التوالي بالمقارنة مع الاساس الموضوع على سطح الأرض.

الكلمات الرئيسية: اساس حصيري، عزم الانحناء، عمق الدفن، منضده هزازة، تربة رملية.

1. INTRODUCTION

For a safe design of the shallow foundation, it must have the ability to resist the dynamic loads; this subject has taken considerable attention in recent years. Embedment has a significant effect on the response of the foundation and must be careful when evaluated, **(Chowdhury and Dasgupta, 2008).** In practice, foundations are located at a certain depth under the soil surface to transmit the structural loads to the soil, this procedure leads to increase the foundation stiffness, **(Al-Azawi, 2006).** Moreover, the energy is dissipated by radiation damping under and along the sides of the foundation, **(Prakash and Puri, 2006)**. In this study the foundation was placed at four different depths to investigate the embedment effect on the generated bending moment during seismic loading. Flexible and rigid raft foundations were used for that reason. The foundations were subjected to three frequencies (1, 2, and 3) Hz, which appointed to minor, intermediate, and substantial earthquakes.

2. MODEL PREPARATION AND EXPERIMENTAL WORK

The soil response is greatly affected by the method of preparation (**Albusoda and Salem, 2012)**. Twenty-four model loading tests were carried out in a rigid steel cylindrical container of (700) mm in diameter and (600) mm in height, the inside walls of the container were covered by styropor sheets to avert the reflection wave during seismic loading which results in extra stresses and intercepts friction of container face and soil. To create a physical model a small scale concrete raft foundation of size (200 × 200 × 10) mm for the flexible raft and (200*200*23) mm for the rigid raft is used. The relative stiffness factor (K) method was applied to determine the thickness that separates flexible raft and rigid by **Eq. (1),** it was equal to (16) mm, (**Gupta, 1997)**. The foundation was reinforced by 30*30 mm steel mesh of 2 mm diameter which represents approximately (1%) of the section area of raft foundation. **Fig.1** shows the modeling of raft foundation. A steel frame of (320) mm in height was firmed on the raft foundation to constitute the building and to carry the additional mass of (40) kg. This mass was determined based on the total allowable settlement of the raft foundation. The building height and the soil layer thickness underlying the raft foundation were fixed to (320) mm and (450) mm, respectively. The used soil was dry dense sandy soil of (70٪) relative density passing through sieve No.10 (2.0) mm and retained on sieve No. (200), properties of the used sand are listed in **Table 1** with the standards of the test**,** hygroscopic water content (≈0.5-3.0%) was added to the sand prior to compaction to ensure small cementation of soil. The soil was placed in the container in layers and then compacted to the needed density, which equals (16.86) KN/m^3 using a steel hammer of (4.5) kg. The height of falling was approximately between (150) and (200) mm, and the number of blows was (4) for each layer, which was decided by fabricating a relation between the number of drops and the resulting dry density. The sand-cone method was used according to **(ASTM-D7698-11a, 1998)** to make sure the required density is achieved. To simulate the earthquake loading, shaking table technique was used, the table was fitted to a fixed displacement equals to 13 mm and (1,2, and3) Hz frequency in x-direction for 10 secs (the earthquake duration), the devices reading continue for 10 secs after the end of operating (the time of free vibration). The used shaking table was manufactured by **(Salem, 2016)**, **Fig.2.**

$$k = \frac{E}{12\,Es}\left(\frac{d}{b}\right)^3 \tag{1}$$

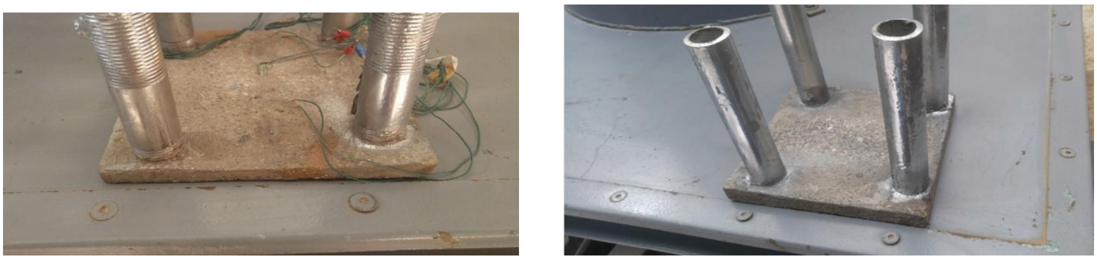
Where:
E = Modulus of compressibility of the foundation in kg/cm^2
E, = Modulus of compressibility of the foundation soil in kg/cm^2
b = Length of the section in the bending axis in cm
d = Thickness of the raft or beam in cm
K= The relative stiffness factor (for K<5 the raft foundation is flexible)

3. INSTRUMENTATION AND MEASUREMENT OF DYNAMIC RESPONSE

To measure the response of the raft foundation the following devices were used:

3.1 Strain Gauges

To measure the generated bending moment three pairs of PFL-20 strain gauges were used. Every pair consist of two gauges fixed at the top and bottom of the foundation and connected by half-bridge technique; these pairs were placed at the raft edges and center.



(a) flexible (b) rigid

Figure 1. Modeling of raft foundation.

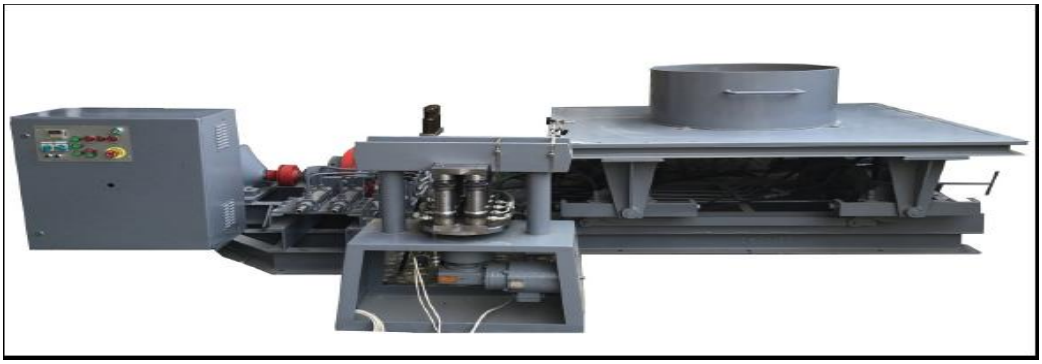


Figure 2. Shaking table photo.

3.2 Data Logger

All the testing devices were calibrated and connected to the data logger unit which provides a connection of these devices with the computer laptop. The data logger consisted of five channels, three of them for half-bridge connection of strain gauges, and two for LVDTs readings.

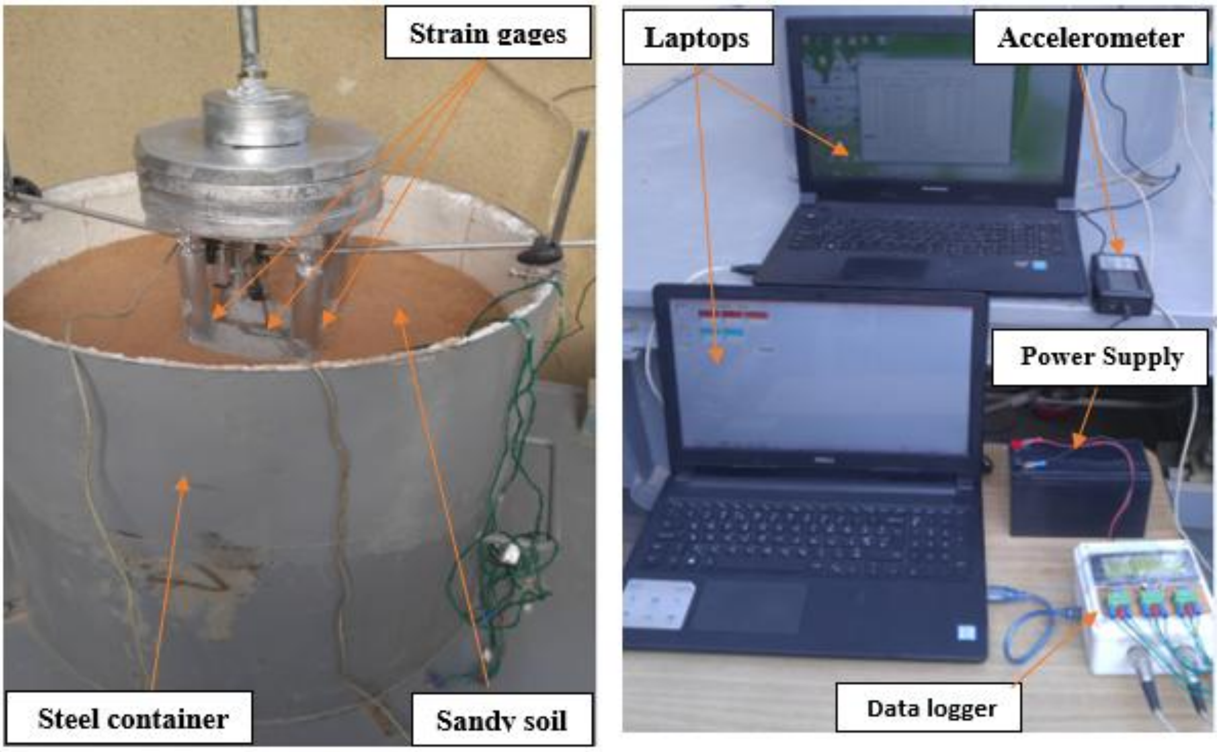
The overall description of test components and measuring devices is shown in **Fig.3.**

4. RESULTS AND DISCUSSION

Bending moment in raft foundation was measured by using three pairs of strain gages located at the edges and the center of the raft; in general, the maximum bending moment was generated at the edge close to the excitation source. **Table 2.** Summarized the recorded maximum bending moment in all the tests.

Table 1. Physical and mechanical properties of the used sand.

Property	Value	Standard of the test
Specific Gravity, Gs	2.68	(ASTM-D854, 1998)
Gravel (> 4.75 mm), %	0	(ASTM-D422-63, 2001)
Sand (4.75-0.075 mm), %	99.5	
Silt and clay (< 0.075 mm),%	0.5	
Unified Soil Classification System (USCS), Soil Type	SP	(ASTM -D-2487, 2006)
Relative Density, RD%	70	–
Maximum dry unit weight ϒdmax , kN / m^3	17.385	(ASTM-D4253-93, 2000)
Minimum dry unit weight ϒdmin, kN /m^3	14.365	(ASTM-D4254-93, 2000)
Dry unit weight (used) ɤd, kN /m^3	16.85	–



(a) testing model (b) testing instruments

Figure 3. General view of the testing model and instruments.

Table 2. Summary of variation the maximum bending moment with embedment depth for (1, 2 and 3) Hz.

embedment depth	raft type	Max bending moment, N.cm		
		1Hz	3Hz	2Hz
0	Flexible	1370	3142	1821
0.25 B	rigid	4215	5098	4588
	Flexible	785	3059	1726
0.5 B	rigid	3311	12387	4243
	Flexible	738	2703	1682
	rigid	2493	18751	3259
B	Flexible	333	1798	1082
	rigid	1622	5363	2889

4.1 Effect of embedment depth

To study the influence of embedment depth of the raft foundation on the generated bending moment under seismic loading the foundation was located at four different depths (0, 0.25B = 50 mm, 0.5 B = 100 mm, and B = 200 mm). **Fig. 4**, **Fig. 5**, and **Fig. 6** show the results of variation bending moment with embedment depth. It was clear from results that the bending moment was reduced with increasing the embedment depth for all excitation frequencies, and for both flexible and rigid foundation except one case, it will be explained later. **Table 3** shows the percentages of bending moment reduction for raft foundation embedded at (0.25 B, 0.5 B, and B) comparing with surface foundation. Increasing the embedment depth means increasing confinement of raft by sidewalls of the basement and surrounding soil which led to reduce the generated bending moment, this trend of behavior wasn't the same for the case of the rigid raft foundation under (3 Hz) which behaved in a different way as in **Fig. 6**. It is explained in the following points:

4.1.1 The maximum bending moment increased with increasing the embedment depth from zero to (0.25 B, and 0.5 B) by (142% and 268%), respectively, compared with surface embedded raft.

4.1.2 The maximum bending moment decreased with increasing the embedment depth from 0.5 B to B by (71%), but it is still more than that of surface embedded raft by (5%).

This behavior may be caused by the influence of the additional inertia resulting from embedment, which was more than that provided by increasing the side friction forces when the embedment depth was increased. When the embedment depth became B the influence of increasing side frictional forces became more than the influence of increasing the inertia forces, and accordingly, the bending moment decreased.

4.2 Effect of raft thickness (rigid and flexible)

The bending moment–time history was recorded for all tests. **Fig.7, Fig.8** and **Fig.9** show the moment – time history for 0.5B embedment depth and (1, 2, and 3) Hz, respectively, which have been chosen to represent the effect of raft thickness on generated bending moment with time. For all tests the maximum bending moment generated in rigid foundation was most larger than recorded in the flexible foundation, this result agrees with (**Aung, and Tun, 2012**) who conclude that the maximum bending moment in raft foundation increases with increasing raft thickness.

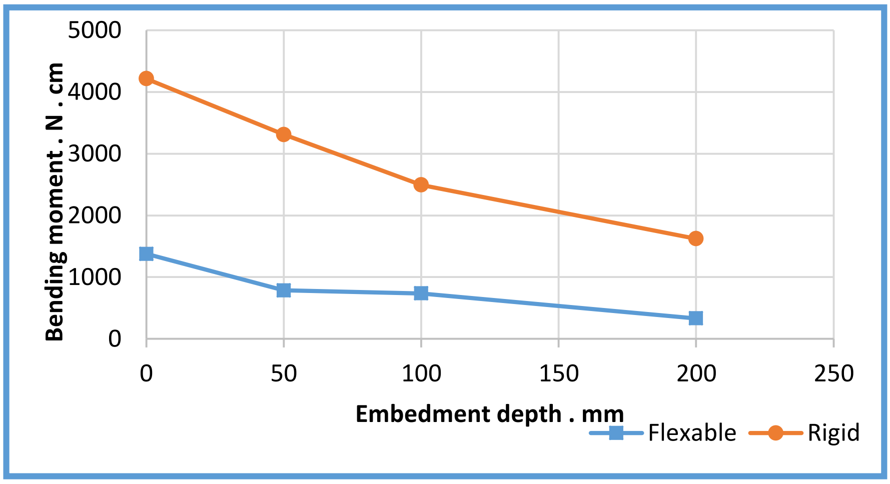


Figure 4. Variation of the maximum bending moment with embedment under (1Hz).

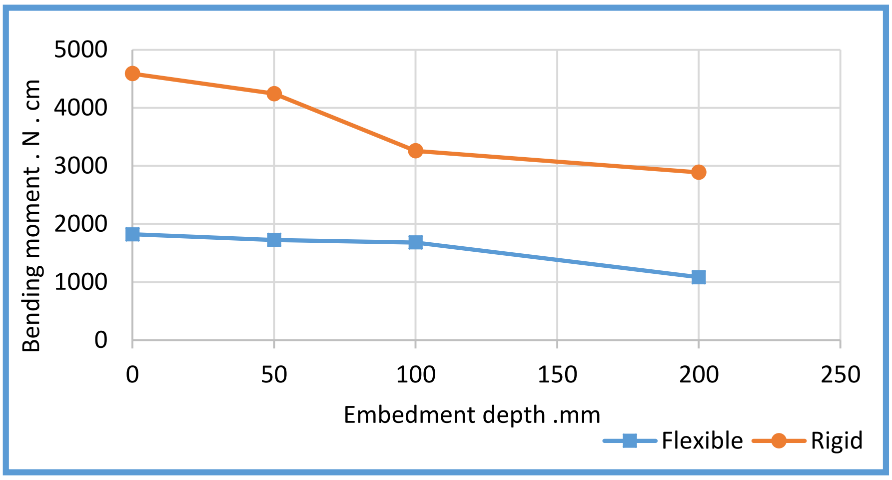


Figure 5. Variation of the maximum bending moment with embedment under (2Hz).

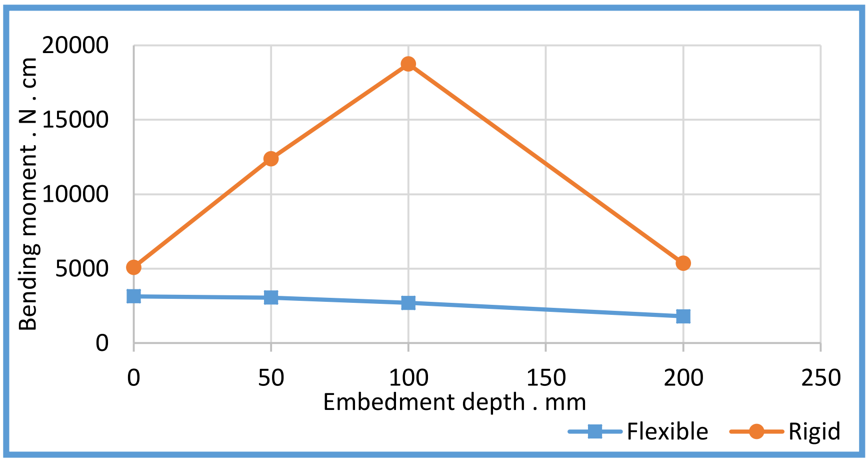


Figure 6. Variation of the maximum bending moment with embedment depth under (3 Hz)

Table 3. Different percentages of the bending moment due to increasing the embedment depth comparing with surface foundation

Embedment depth	Raft foundation type	Different percentage comparing with surface foundation, %		
		1 Hz	2 Hz	3 Hz
0.25 B	Flexible	-43	-5	-3
	Rigid	-21	-8	+143
0.5 B	Flexible	-46	-8	-14
	Rigid	-41	-29	+268
B	Flexible	-76	-41	-43
	Rigid	-62	-37	+5

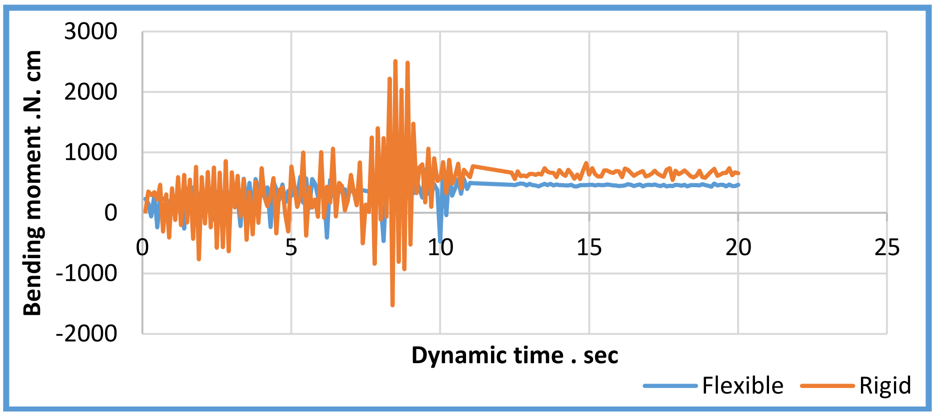


Figure 7. Bending moment - time history at 0.5 B embedment depth under (1Hz).

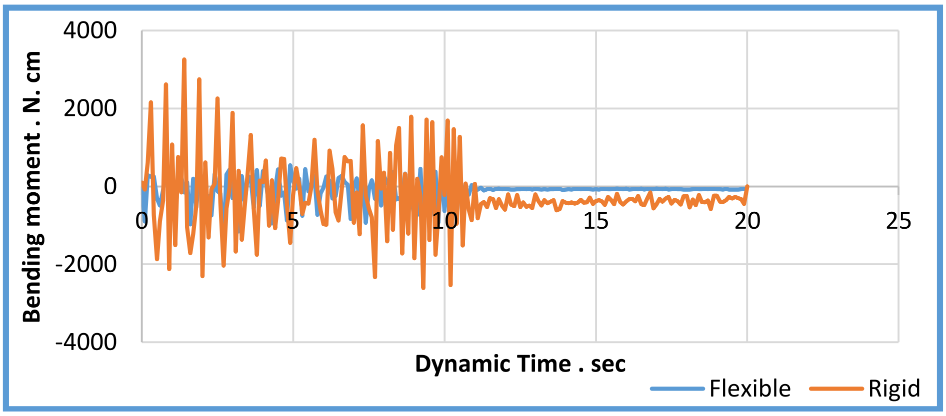


Figure 8. Bending moment - time history at 0.5 B embedment depth under (2 Hz).

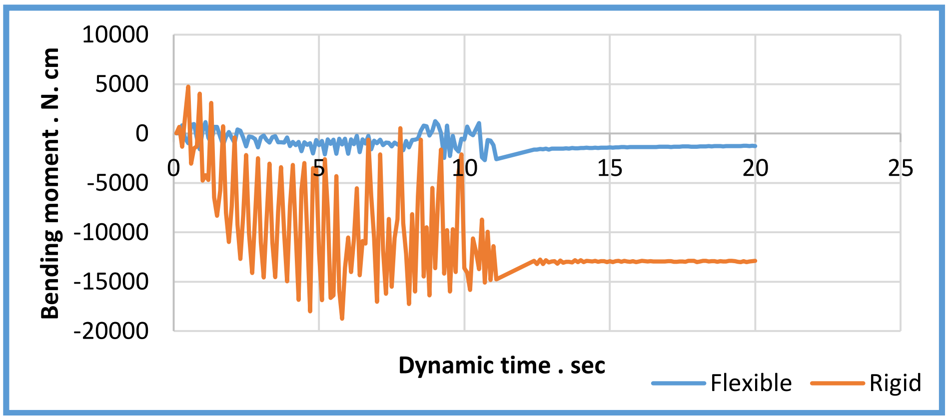


Figure 9. Bending moment – time history at 0.5 B embedment depth under (3 Hz).

Table 4. summaries the ratio of maximum bending moment generated in the rigid raft to that of the flexible raft foundation. The higher stiffness for the rigid raft means more resistance to the shape change when subjected to seismic loading, and that led to higher internal forces and bending moment generated in the raft foundation (the moment is a function of the force).

Table 4. Summary of the maximum bending moment generated in the rigid raft to that generated in flexible raft.

Embedment depth	(Rigid / Flexible) maximum bending moment		
	1Hz	2Hz	3Hz
0	3.1	2.5	1.6
0.25 B	4.2	2.5	4
0.5 B	3.4	1.9	6.9
B	4.9	2.7	3

4.3 The effect of excitation frequency on bending moment

The raft foundation was subjected to three different excitation frequencies (1, 2, and 3) Hz, for both flexible and rigid raft foundation, and for all embedment depths, the variation of bending moment was as shown in **Fig.10**, and **Fig.11.** From figures, it's clear that higher frequency led to generate higher bending moment in the flexible and rigid raft foundation because higher frequency means higher applied forces, which leads to higher bending moment as the moment is a function of loading. **Table 5** summarizes the ratio of maximum bending moment generated in raft foundation excited by (2 and 3) Hz to excited by (1Hz). Generally, the ratios related to flexible raft were higher than those of rigid rafts because the higher ability of vibration damping of rigid raft foundation.

5. CONCLUSIONS

- Generally, the maximum bending moment decreased with increasing embedment depth. With increasing the embedment depth from zero to B, the maximum bending moment decreased by (75%, 41%, and 43%) for flexible raft under (1, 2, and 3) Hz respectively, for rigid raft the maximum bending moment decreased by (62%, and 37%) under (1 and 2) Hz respectively.

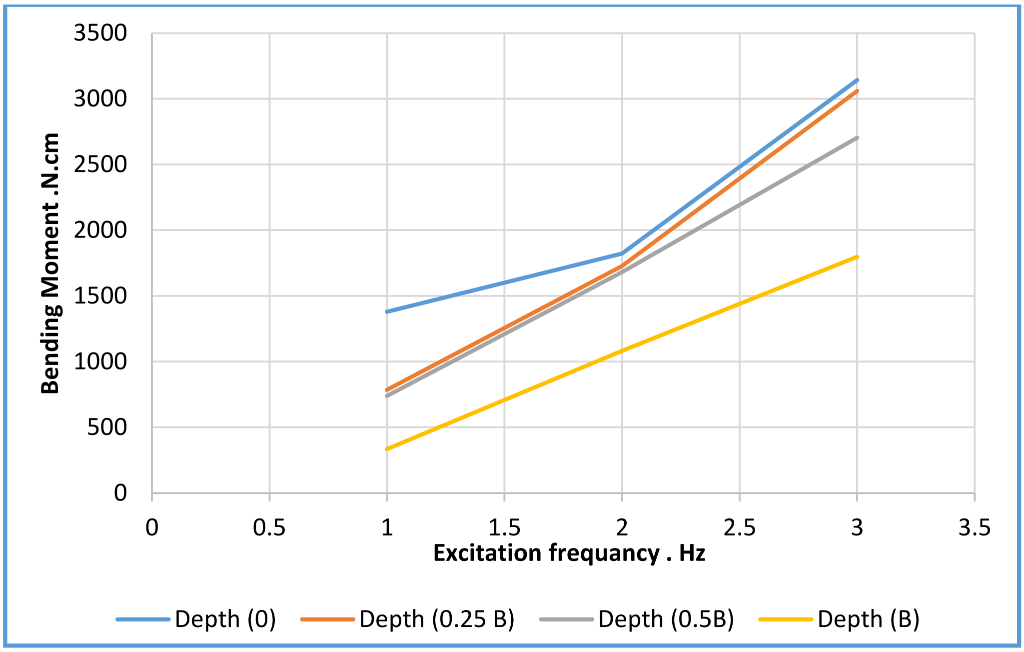


Figure 10. Variation of maximum bending moment of the flexible raft foundation under different earthquake excitation frequency.

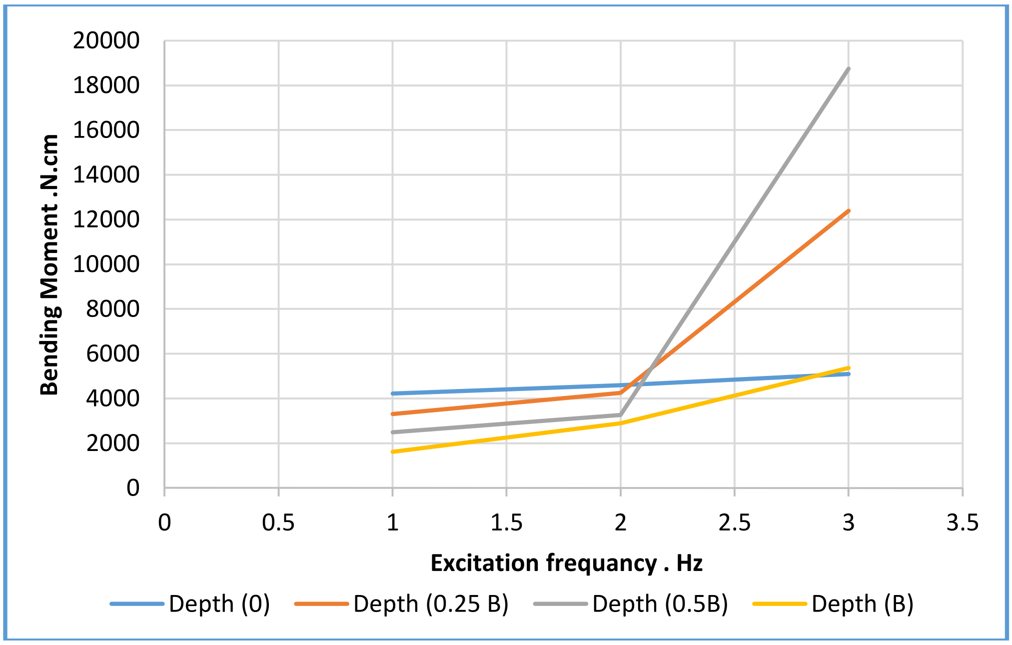


Figure 11. Variation of maximum bending moment of rigid raft foundation under different excitation frequency .

Table 5. Summary of bending moment of (2 and 3) Hz to that of (1Hz) in the flexible and rigid raft foundation.

Embedment depth	Raft type	(2Hz/1Hz) maximum bending moment	(3Hz/1Hz) maximum bending moment
0	Flexible	1.3	2.3
	Rigid	1.1	1.2
0.25 B	Flexible	2.2	3.9
	Rigid	1.3	3.7
0.5 B	Flexible	2.3	3.7
	Rigid	1.3	7.5
B	Flexible	3.3	5.4
	Rigid	1.8	3.3

- For 3Hz excitation frequency, the trend of behavior wasn't the same for the case of rigid raft foundation as the maximum bending moment increased with increasing the embedment depth from zero to 0.25B and 0.5B by (143% and 268%) respectively, compared with raft foundation of zero embedment depth, however, as the foundation embedded at B, the maximum bending moment decreased by (71%) compared with raft foundation of 0.5B though it still higher than that of zero embedment depth by (5%).
- Increasing the excitation frequency increases the maximum bending moment of flexible and rigid raft foundation.
- Generally, the maximum moment is measured at the edge close to the direction of starting the dynamic excitation of the foundation. Also, significantly higher maximum moment values were measured in rigid raft foundation comparing to the flexible one.
- The maximum bending moment is significantly affected by raft thickness; very high readings were recorded for the rigid raft foundation comparing with the flexible raft foundation.
- The ratio of the maximum bending moment generated in the rigid raft foundation to that generated in flexible raft foundation ranged between (1.6 to 6.9).

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b = length of the section in the bending axis, cm
B=raft foundation side length, mm
d = thickness of the raft or beam, cm
E = modulus of compressibility of the foundation, kg/cm^2
E, = modulus of compressibility of the foundation soil, kg/cm^2
K=the relative stiffness factor (for K<5 the raft foundation is flexible