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Studying the Behaviour of a Proposed Strip Foundation for Structural Retrofitting

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Abstract

One of the remedies to strengthen the existing buildings is to add either concrete or steel frames to the structure. To execute this design, it is necessary to build foundations that usually will be located under existing walls. Considering the fact that the walls are carrying loads, addition of foundations beneath the walls in traditional ways is not possible. Thus the retrofitting experts introduced some practical procedures to fulfill the job. In most of these procedures, the foundations are built piece by piece separately and then patched to each other. Foroughi proposed a type of foundation called Khorjini foundation. In this proposed type, two parallel strips will be built in both sides of the existing wall and they are connected to each other at the column locations. Studies done by Foroughi et al. show the desired functioning of this type of foundation. In these studies, the proposed samples are designed by using ETABS based on standard regulations. Then, the foundations are analyzed by finite element considering material and geometrical nonlinearities by employing SAFE and ANSYS. The results show that in addition to simplicity, low cost and high quality, the safety during construction was much higher.

Keywords: foundations, khorjini, saddle- like, khorjini foundation, rehabilitation, strip foundation.

1 Introduction

Retrofitting of structures is a subject that attracted attention of researchers in recent decades and resulted in introducing new methods and materials [1]. One of the desired methods especially in cases of low rise masonry buildings is adding of new steel or concrete frames and joining them to the building so that the combination is able to behave safely under applied loads especially in case of earthquake.
In most cases, the designed foundation locates under the load carrying walls [2]. Construction of such foundations as a whole is not possible because excavating

beneath the load carrying wall at a considerable area is dangerous, costly and almost impossible. Thus, construction of partial strip foundations in gradual timetable is introduced [3]. These methods are costly and time consuming and in addition, because of patching different portions at various points, are considerably weak.
To overcome these difficulties, in retrofitting procedure of a masonry building, Foroughi introduced an alternative method called Khorjini foundation [4]. In this method the foundation shape is similar to car chassis. Such that the foundation is constructed as two strips at both sides of the wall and then the two strips are connected to each other at column locations in a limited region. The main advantage of the method is construction of the foundation completely compared to traditional partial construction resulting in operational-speed, and cost reduction. Another advantage that could be more important is no need for excavation beneath the wall. This will increase the safety and prevent future settlement of the wall. Also, since the wall can function completely during the operation interval, it is not necessary to use shoring to carry the roof load causing the safety of the operation to be high. In this research, behavior of this type of foundation is compared to other types by modeling the foundation employing ANSYS and considering nonlinearity.

2 Introducing traditional partial foundation

In traditional methods, the foundation is constructed part by part in gradual stages (Figure 1) [3]. After shoring the roof and transferring the load from wall, underneath the wall is excavated in a limited length depending on the wall and soil characteristics (Figure 1) .For example in a regular case the range of excavation can be about one meter after each two meter undisturbed. Then after excavation, and placing formwork and prepared reinforcement bars the concrete will be poured (Figure 1). After curing the concrete and reaching the ultimate load carrying capacity, the following portion of the wall is excavated and similarly, after formwork and placing the reinforcement, the bars are welded to the folded bars of previous portion (Figure 2) and the concrete will be poured. This procedure will be repeated until the whole wall is covered (Figure 3).

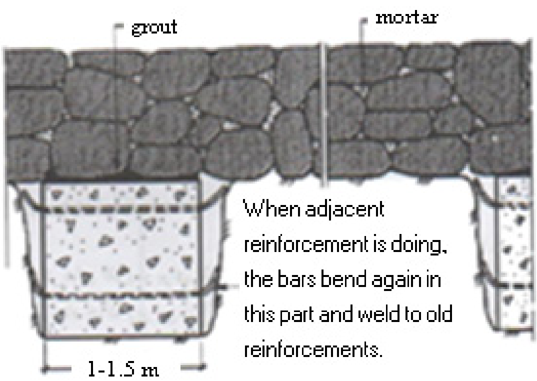

Figure 1: Part by part performance of strip foundation

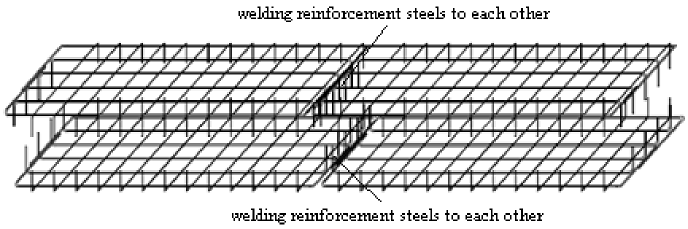

Figure 2: Welding of reinforcement steel bars in part by part performance of strip foundation

This method is normally used for maintaining foundation for load carrying walls but it can be used for new frame foundation by considering necessary observations. For example, to include columns, in location of the columns, the necessary bars can be placed for continuation of concrete columns or bolts for base plates can be maintained for steel columns.

Figure 3: A strip foundation was performed under an existing wall in a steel frame structure by part by part method

3 Introducing khorjini foundation

This type of foundation was first introduced by Foroughi in 2005 in retrofitting of a masonry building project [4]. In this method, as mentioned before, the Khorjini foundation will be formed as two parallel strips in opposite sides of the wall connected to each other at column locations (Figures 4 and 5). The column load will be transferred to the foundation by passing through base plate and connector of two strips [4]. In this design, because of confinement of the wall by the foundation, a portion of wall load will be transferred to foundation thus, in addition to carrying load; the foundation will act as a tie beam. In this method, during operation except in a limited area the wall is based on soil so the load carrying capacity of the wall will not be reduced during operation. This situation will minimize the operational time and the speed and safety of operation will be much higher than the traditional one discussed before. Foroughi et al [5, 6, and 7] have shown that the amount of concrete and reinforcement used in this design are almost equal to traditional strip foundation [7].

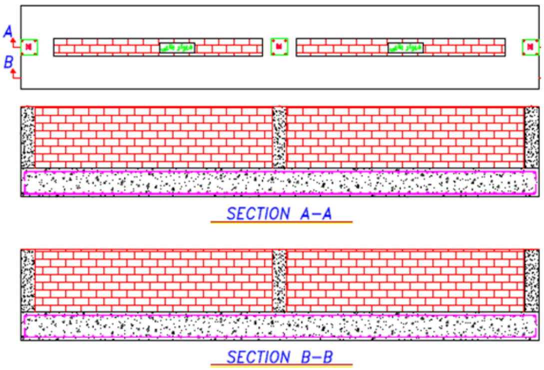

Figure 4: A Khorjini Foundation

Figure 5: Performing of a Khorjini Foundation

4 Modeling of foundation samples

In this section, the finite element modeling of both traditional and Khorjini strip foundations employing ANSYS software considering nonlinear behavior will be discussed [7]. A practical building that need addition of a 3 span steel frame combined of two steel columns and a continuous beam that at two ends is fixed to masonry walls are considered and studied in 4 different conditions;

[1] Simple steel frame with fixed supports to the foundation
[2] Rigid steel frame with fixed supports to the foundation
[3] Rigid steel frame with hinged connections to the foundation.
[4] Hinged braced steel frame with hinged connection to the foundation

All 4 samples are analyzed and designed by ETABS [8] subject to gravity and earthquake loads according to Iranian national codes [9, 10]. Finally, the base reactions were transformed to SAFE and the strip foundation was designed by this software. Then the Khorgini foundation was designed using the same procedures. The index for design of both types of foundations was the maximum stress in the soil under foundation so that the maximum stress at both cases considered being equal. Then the Khorgini foundation and its reinforcement were designed by SAFE [11]. Finally, the behavior of Khorgini foundation was studied using ANSYS [12] and compared with the traditional strip foundation.

4.1 Finite element modeling of foundations

The modeling of foundations is discussed below:

a- The foundation body was modeled employing SOLID65 (Figure 6) elements considering all necessary observations such as suitable aspect ratio (Figure 7). Using these elements enables designer to include reinforcement and cracking.

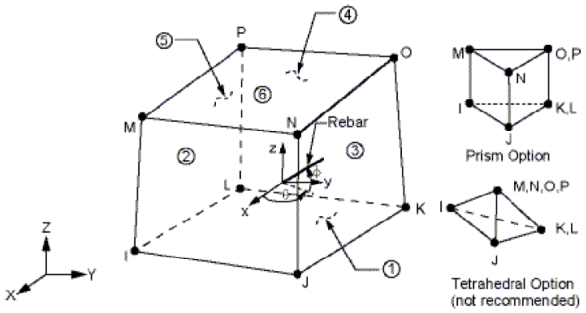

Figure 6: A SOLID65 element

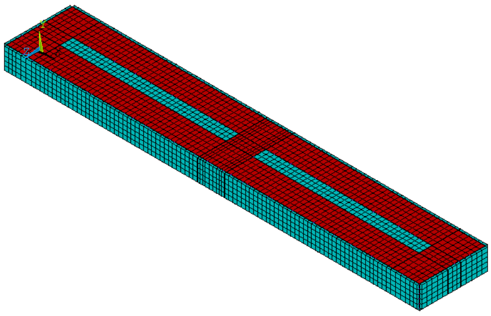

Figure 7: Finite Element model of Khorjini Foundation

b- The masonry wall was modeled using the same element (SOLID65) but without reinforcement.

c- The soil confining the foundation was modeled as fixed support. The contact surface of foundation with soil and wall was modeled using three dimensional contact elements CONTAC52 (Figure 8). These elements function so that the adjacent nodes can transfer compression but in case of tension, the relation between the two nodes is released so that no tension will exist and the nodes can move independently. Also these elements are capable of modeling Coulomb friction in contact.

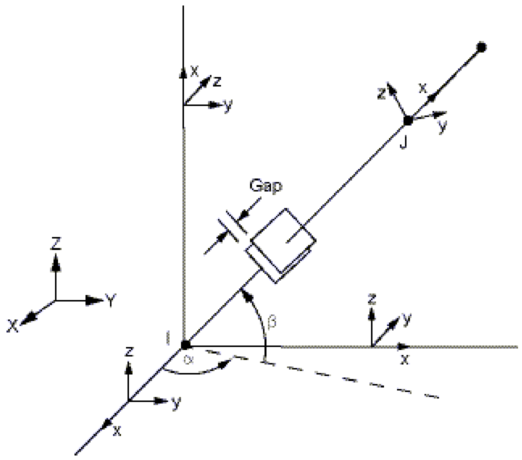

Figure 8: A CONTAC element

d- Loading of foundations are cyclic loads at base plate region assuming fixed elements. These loads are actually the base shear obtained from steel frame analyses by ETABS. To analyze the frame, it is modeled and the gravity dead and live loads are applied. Then the frame will be subjected to cyclic lateral displacements at roof level in the beam direction. The loading will be applied according to AISC [13] (Figure 9). At each loading stage, the support reactions obtained from ETABS analyses will be applied to the ANSYS modeling of the foundation.

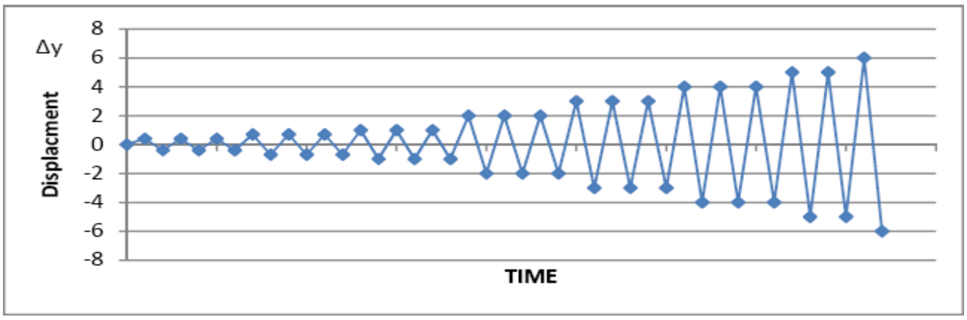

Figure 9: Cyclic loading according to AISC

4.2 Results discussion

Some of the results obtained will be discussed as follows;

a- Rigid frame with fixed supports
Figure 10 shows contours of stress in concrete body at ultimate loading stage both in strip foundation and khorgini foundation. We can see that Khorgini foundation has no weakness compared to strip foundation. Figure 11 shows contours of stress in soil under foundation at ultimate load stage for both cases. Comparison of the curves shows no disadvantage in case of khorgini foundation.

b- Rigid frame with hinged supports
Figure 12 shows contours of stress in concrete body at ultimate loading stage both in strip foundation and khorgini foundation. Figure 13 shows contours of stress in soil under foundation at ultimate load stage for both cases. Comparison of the curves shows no disadvantage in case of khorgini foundation.

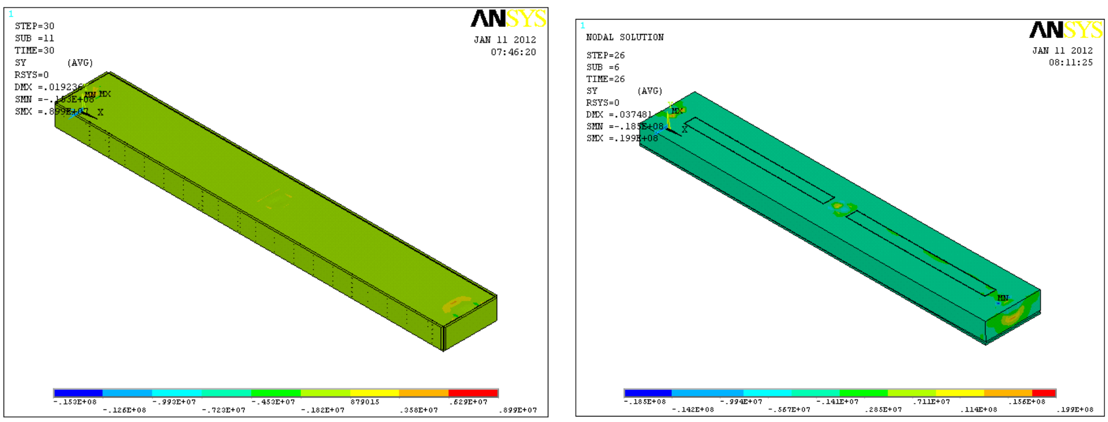

Figure 10: Stress contours in concrete body at ultimate loading stage in strip foundation and Khorjini foundation (rigid frame with fixed support)

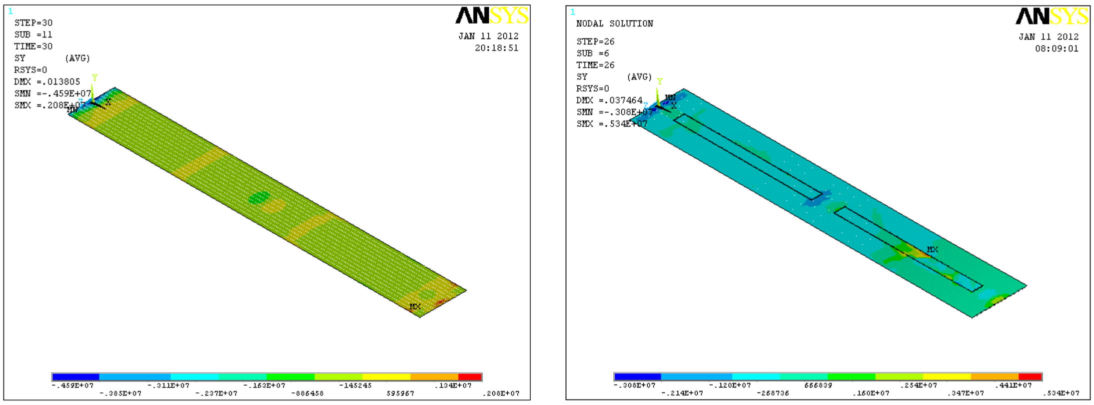

Figure 11: Stress contours in soil at ultimate loading stage in strip foundation and Khorjini foundation (rigid frame with fixed support)

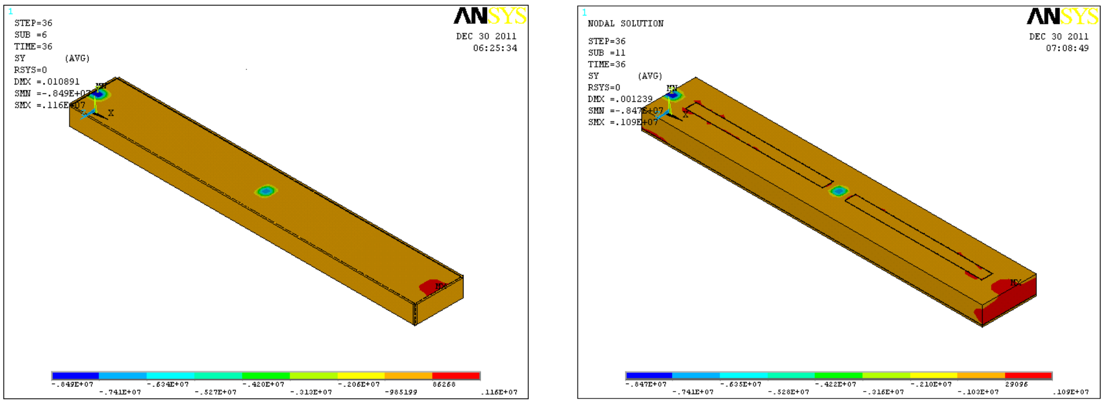

Figure 12: Stress contours in concrete body at ultimate loading stage in strip foundation and Khorjini foundation (rigid frame with fixed support)

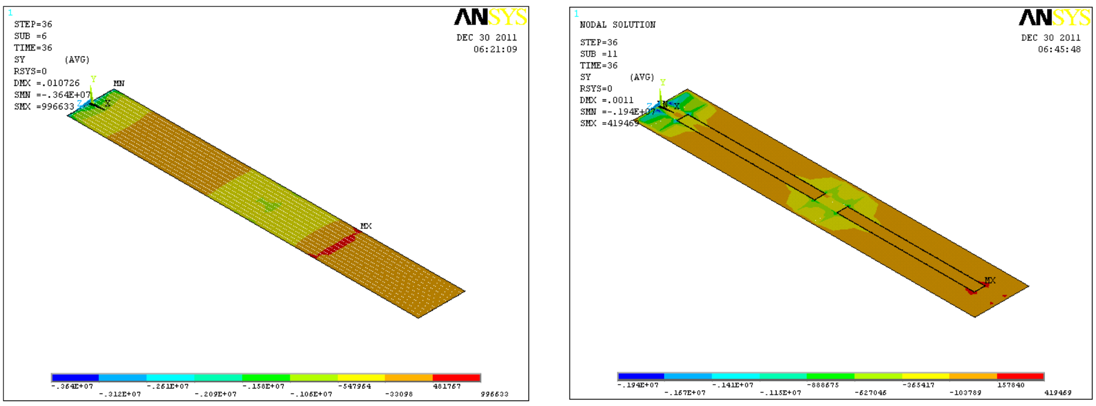

Figure 13: Stress contours in soil at ultimate loading stage in strip foundation and Khorjini foundation (rigid frame with fixed support)

c- Hinged frame with fixed support (no bracing)

Figure 14 shows contours of stress in concrete body at ultimate loading stage both in strip foundation and khorgini foundation. Figure 15 shows contours of stress in soil under foundation at ultimate load stage for both cases. We can see that Khorgini foundation has no weakness compared to strip foundation.

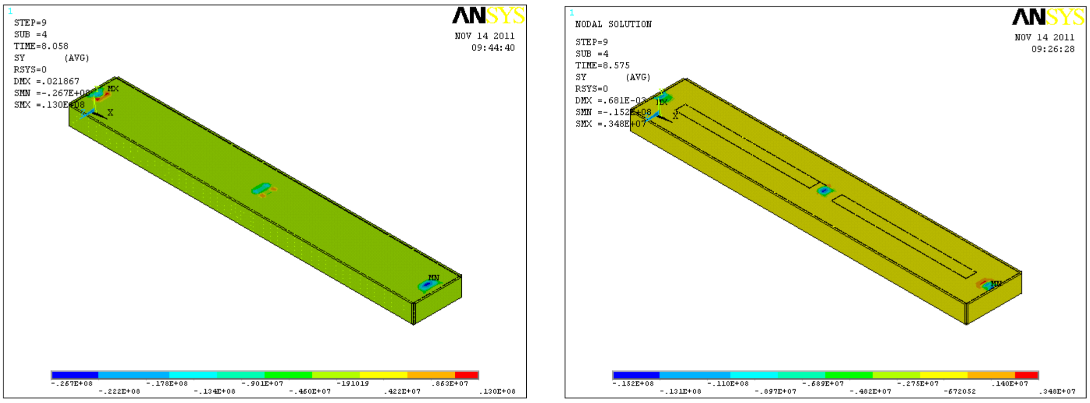

Figure 14: Stress contours in concrete body at ultimate loading stage in strip foundation and Khorjini foundation (hinged frame with fixed support)

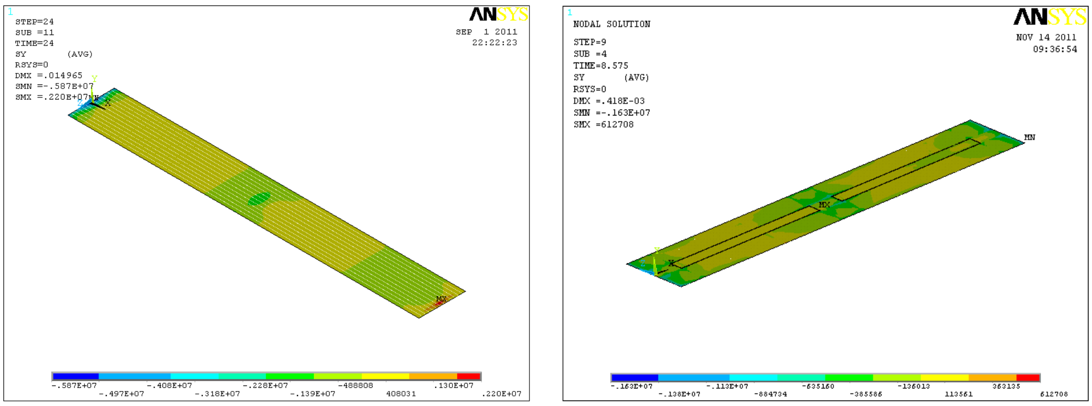

Figure 15: Stress contours in soil at ultimate loading stage in strip foundation and Khorjini foundation (hinged frame with fixed support)

d- Hinged frame with hinged support (with bracing)

Figure 16 shows contours of stress in concrete body at ultimate loading stage both in strip foundation and khorgini foundation. Figure 17 shows contours of stress in soil under foundation at ultimate load stage for both cases. Comparison of the curves shows no disadvantage in case of khorgini foundation.

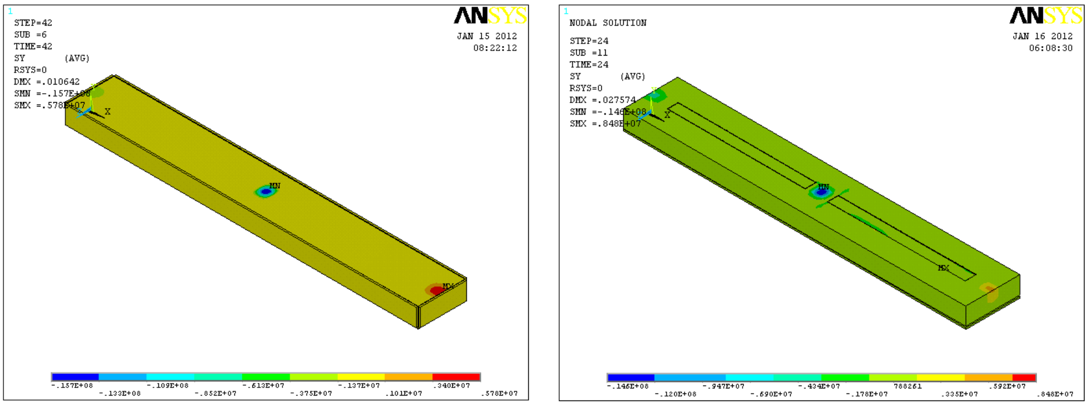

Figure 16: Stress contours in concrete body at ultimate loading stage in strip foundation and Khorjini foundation (hinged frame with hinged support)

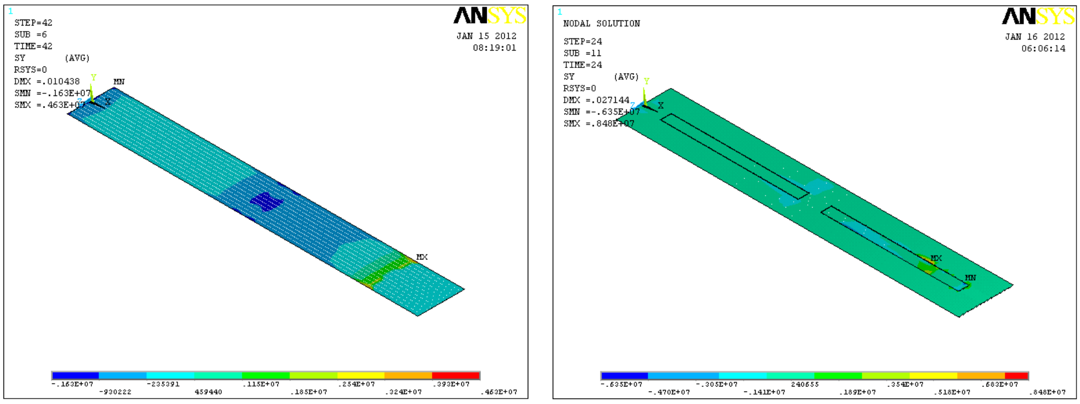

Figure 17: Stress contours in soil at ultimate loading stage in strip foundation and Khorjini foundation (hinged frame with hinged support)

Comparing all cases shows that khorgini foundation behaves as well as strip foundation. In figure (18) the performance costs of Khorgini foundation and strip foundation is compared. It can be observed that the cost of Khorgini foundation is considerably less than strip foundation. The reason is operation tasks involved in strip foundation. It is clear that because of continuity of operation, the speed in case of khorgini foundation is higher than strip foundation. As already mentioned, the safety of operation of khorgini foundation is much higher.

5 Conclusions

In retrofitting of buildings, if there is a need for construction of strip foundations underneath the existing walls, operation of khorgini foundation is the best choice due to following reasons;

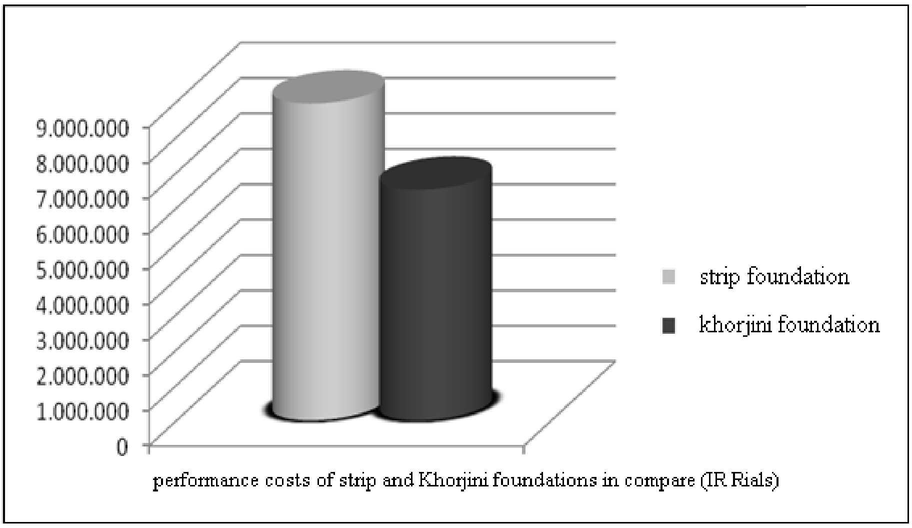

Figure 18: The performance costs of Khorgini foundation and strip foundation in compare

1. Since it is not possible to excavate total length of the wall, either part by part excavation of the wall can be considered or khorgini foundation must be applied.
2. In construction of a khorgini foundation the wall base will be excavated only at column location thus, the safety of operation is high and the wall will be stable during operation.
3. The concrete volume in the khorgini case is almost equal to strip foundation. The reinforcement steel weight in case of strip foundation is more than khorgini case because of partial operation. In general, if all costs of operation including formwork, piling etc are compared; construction of khorgini foundation is more economical.
4. With respect to the continuity of the concrete and the reinforcement, from a structural point of view, the khorgini foundation is preferred.
5. The speed of construction for a khorgini foundation is considerably higher.
6. A study of stress and strain and deformations in both cases shows no disadvantage in khorgini foundation.

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