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Excavation of disposal wells nearby existing buildings effects and design precautions

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ABSTRACT: Excavation of wastewater disposal wells in residential building is a common practice in Sudan. However, the ground movement due to excavation is not considered in the design stage of these buildings. This paper aims to study the effect of ground movement due to excavation of wastewater well in structural performance of adjacent buildings. In this study, the excavation induced settlements are initially predicted using empirical models and calibrated against finite element results. Then the structural performance was assessed for different magnitudes of settlements at outer isolated footings in a typical one to five storey buildings. The results demonstrate the importance of considering the ground movement due to wastewater disposal well in design stages to ensure safe design.

1 INTRODUCTION

The conventional sewerage systems in Sudan are very limited, for example it covers only 7% in Khartoum state. Therefore, wastewater disposal well are used heavily and excavated very near to building isolated footings for a depth exceeding 10 meters and a diameter ranging from one to two meters (Fig. 1). The excavation of circular unsupported wells always induces unfavourable vertical and horizontal ground movement. These movements are usually ignore in the structural design. These movement result in differential settlement in isolated footings causing additional stresses, moments, shear forces, and axial forces that have to be considered to insure safe design. The aim of this paper is to study the effect of ground movement due to excavation of wastewater well in structural performance of adjacent buildings.

The paper is organised in five main sections. In Section 2 a background about the prediction of ground movement due to excavation and expected damages was given. In Section 3 a comparison of finite element and numerical model results was carried out. In Section 4 an example of structural performance of frame structures subjected to ground movement due to well excavation is presented. Results are discussed in Section 5. Finally, conclusions are given in Section 6.

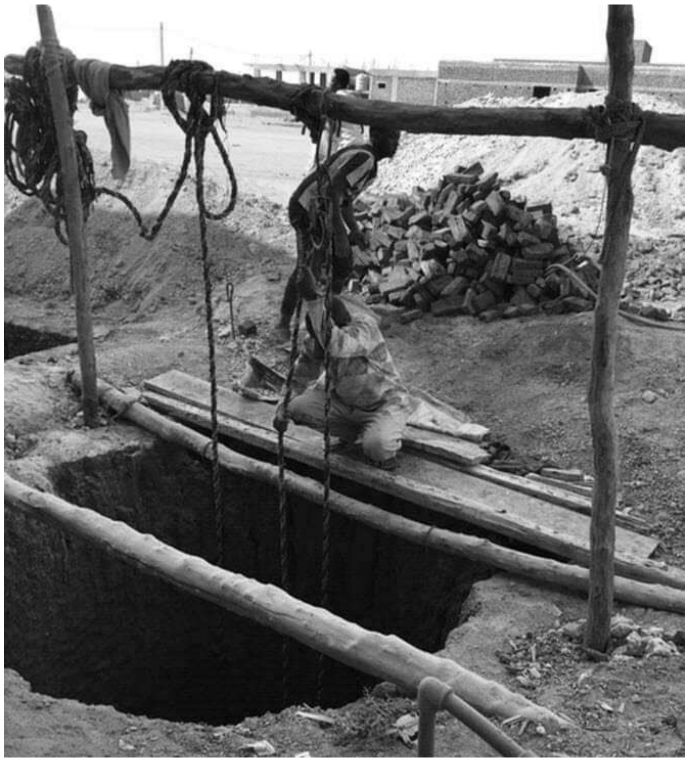

Figure 1. Manual Excavation of Wastewater Disposal Well – Khartoum

2 BACKGROUND

2.1 *Damages due to ground movement*

Excavation work for disposal wells or for utilities always cause ground movements in soil under the foundation of the adjacent buildings. These soil movements due to excavation induce vertical settlement and longitudinal displacement which may lead to structural failure or cracks in the existing buildings.

Skempton & MacDonald (1956) propose a limit building rotation for framed buildings. It is stated that structural damage is expected at a relative rotation of 1/150 while the cracks are expected in infill walls at a relative rotation of 1/300. They consider 1/500 is the safe limit for cracking.

Burland et al. (1977) suggested six categories of damages associated with building settlement, numbered from 0 to 5 with increasing severity. The classification is based on the ease of repair of visible damage to the building fabric and structure. For most cases, Categories 0, 1 and 2 can be taken to represent 'aesthetic' damage with crack width of 0.1 mm, 0.1 - 1 mm, 1 - 5 mm, respectively. Categories 3 and 4 'serviceability' damage with crack width ranging from 5-15 mm, 15-25 mm, respectively. In Category 5 'stability' damage, typical crack widths are greater than 25 mm.

However, the prediction of damages in existing building adjacent to wastewater disposal well in construction is not easy to be identified due to lack of relative previous studies and numerical models.

2.2 *Prediction of ground movement due to excavation*

While many models are suggested to predict the ground movement due to rectangular excavation, very limited models are developed for circular excavations.

New & Bowers (1994) conducted a well-documented case study on an 11 meter diameter circular shaft that has been frequently used to predict ground movements. The case study dealt with a deep circular shaft for the Heathrow Express trial tunnel that was sunk in London Clay. A parabolic empirical formula for the surface settlement S_v (d) behind the shaft wall was suggested:

$$S_v(d) = \frac{\alpha(H-d)^2}{H} \quad (1)$$

Where α, taken as 0.0006, is a constant depending on the method of construction and soil conditions. Application of Equation 1 for small diameters introduces some uncertainty since this equation was developed for a circular shaft of a diameter of 11 meters and 26 meters depth and different drilling method. However, with the absence of the field observation and empirical model for shafts with small diameter this equation will be used in this study. The equation will be calibrated using the finite element method to correct the factor α for the considered case study in this paper.

3 FINITE ELEMENT MODEL

In this part, finite element modelling of excavation of unsupported wastewater disposal well was carried out using PLAXIS 2D finite element (FE) software. Very recent soil data were used from a geotechnical report carried on a plot in Khartoum State, in Geraif East area which is topographically classified as clayey soil. The FE inputs of soil properties and wastewater disposal well geometry are given in Table 1.

Table 1. Disposal well geometry and soil properties FE inputs

Parameters	Value
Wastewater disposal well geometry:	
Depth	10 meters
Diameter	2 meters
Soil properties:	
Density	18 kN/m^3
Angle of friction	35 degree
Soil stiffness (EI)	56525 kN.m^2

The FE analysis was carried for different distances of the nearest isolated footing to the excavation face. Both vertical and horizontal displacement were presented in contour format. In this paper, only a sample of FE results are presented for footing distance of 1.0 meter as shown in Figure 2.

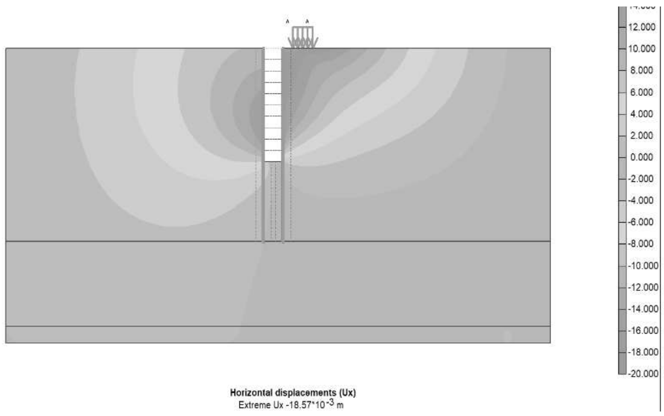

Figure 2. Horizontal Settlements for 1.0 m footing distance

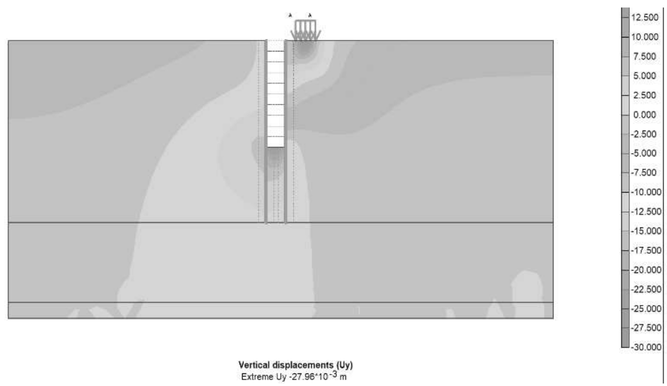

Figure 3. Vertical Settlements for 1.0 m footing distance

Table 2 shows the FE predictions of the vertical settlement for distances of 0.5 m, 0.8 m, 1.0m, 1.3 m, 1.5 m, 2.0 m, 2.5 m, 3.0 m, 4.0 m from the excavation face to the nearest isolated footing. These distances represent the common range in Sudan. Also factor of α in Equation 2 is back calculated. It is found that the average of factor α for this example is 0.003. This value could be used in Equation 2 to calculate structural response of the case study in this paper.

Table 2. Vertical settlements at different footing distances from face of excavation

Footing Distance (m)	Settlement (m)	α
0.5	0.0274	0.0030
0.8	0.0240	0.0028
1.0	0.0225	0.0028
1.3	0.0208	0.0027
1.5	0.0201	0.0028
2.0	0.0196	0.0031
2.5	0.0195	0.0035
3.0	0.0197	0.0040

4 STRUCTURAL RESPONSE DUE TO DISPOSAL WELL EXCAVATION

The case study of the research is a five floor (ground floor plus four typical floors) residential building located El-Geraif area in Khartoum. The building area is 340 m^2 with normal finished flats. An equivalent 2D frame, Figure 4, of the building was analysed using Axis VM 10 + software considering the ground movement due to excavation at the outer footing. The disposal well was assumed to be in line with the selected frame.

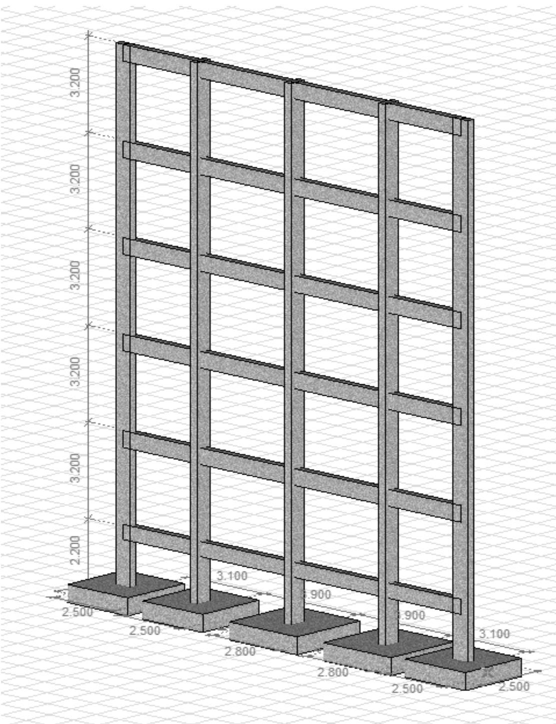

Figure 4. Equivalent 2D frame of the building

5 RESULTS AND DISCUSSIONS

The structural performance was assessed for 5, 10, 15, 20, and 25 mm vertical settlement and longitudinal displacement (s). The assessment considers the sway of the building, rotation of the lower bay, axial force in the first interior column, and bending moment in the lower and first interior beam. All these loads are compared to those occurred from the service design loads for different number of floors, Figure 5. All analyses are carried out considering the distance of footings to the excavation face is two meters.

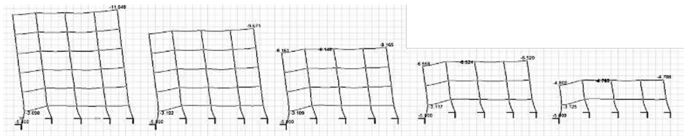

Figure 5. Applied settlement at the outer footing

5.1 *Building sway*

The building sway is assessed by measuring the horizontal displacement at the edge of the top floor as shown in Figure 6. It is clear that the top sway increases with an increase in building height and the amount of the settlement.

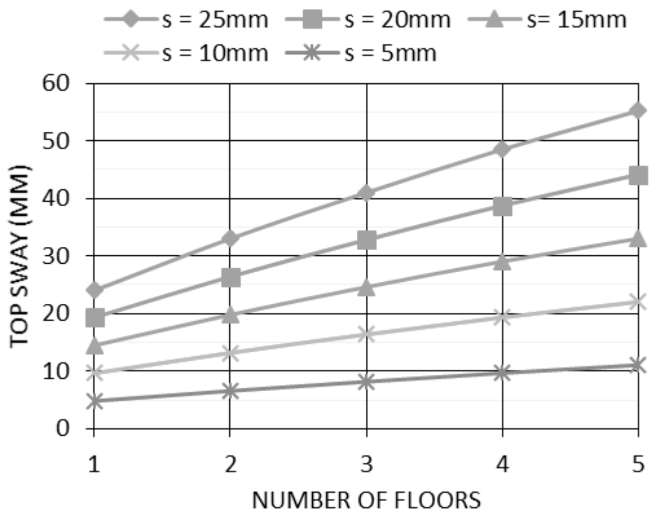

Figure 6. Building top sway for different number of floors for different horizontal and vertical Settlements

5.2 *Building Rotation*

Building rotation in this study is measured at the lower bay. As mentioned early in Section 2.1, the cracks are expected to occur at infill walls and partition if the relative rotation exceeds 1/300 (3.3E-3). As demonstrated in Figure 7, the results show that rotations associated with settlements more than 5 mm exceeding this limit. Therefore cracks are expected to appear for these cases. Usually the safe limit for cracks is set to 1/500 (Goh 2008)

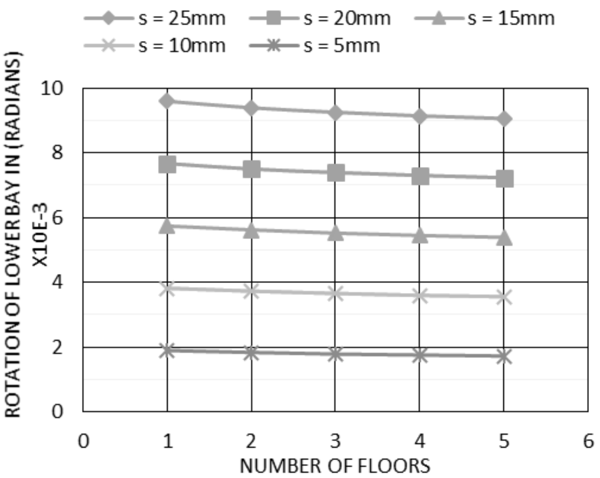

Figure 7. Building rotation for different number of floors for different horizontal and vertical Settlements

5.3 *Axial force at the lower Bay first interior Column*

In this part, the ratio of the axial force after footing settlement to the axial force before the settlement took place for the first interior column at the lower bay is presented. The results shown in Figure 8 show a massive increase in the axial force after the settlement was applied to the system, nearly 4 times in the case of 25 mm settlement, which is not expected. An additional analysis was carried out after removing the support at the outer footing location (No soil support – Free hang). It was found that the maximum deflection at this point was 13 mm. This means the frame will not be able to settle more than 13 mm at this point. Therefore, applied settlements more than that are regarded as impractical (i.e. not possible) and only help to understand the general structural behaviour of a structure subjected to ground movement due to circular excavation. It is also important to account well-soil-structure interaction to have a better understanding.

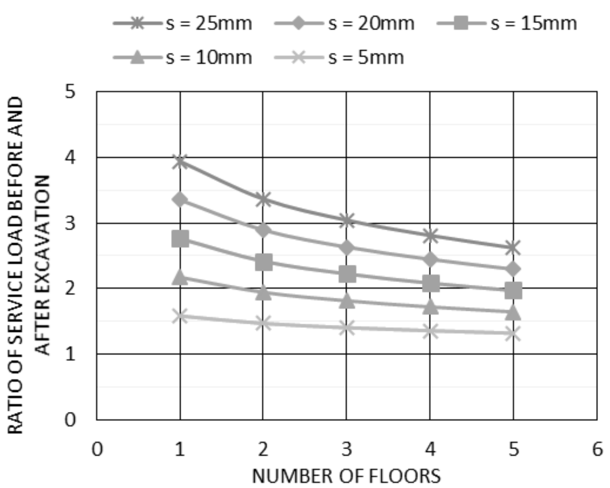

Figure 8. Ratios of axial forces before and after excavation at different number of floors for different horizontal and vertical Settlements

5.4 *Axial force at the lower Bay first outer Column*

The outer column, where the settlements are applied, is mainly subjected to a tension force to have the targeted settlements. Therefore, it is expected to have a reduction in the applied force. Figure 9 shows that for settlement more than 5 mm the columns become subjected to tension force (given in positive sign) rather than compressive force (given in negative sign). For possible range of settlement as shown previously (< 13 mm), it is expected to have 250 kN less tension force.

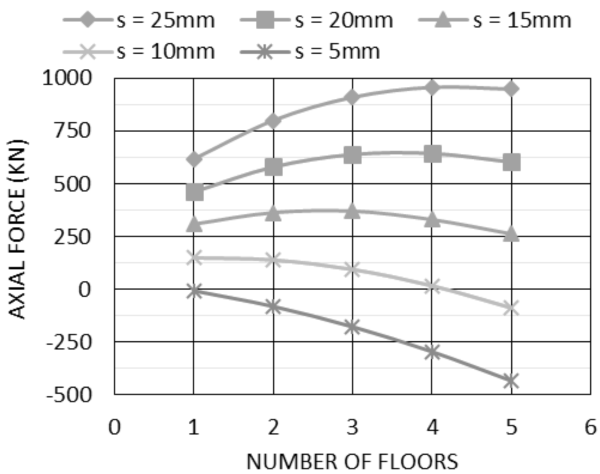

Figure 9. Reaction at the outer columns for different number of floors for different horizontal and vertical Settlements

5.5 *Bending moment of Beam first span at the lower bay*

Settlement of a support is known to cause a fixed end moment for a beam related to the magnitude of the settlement (i.e. = $\pm 6EI\Delta/L^2$). For this case the maximum bending moment for this beam is plotted for different number of floors and settlements in Figure 10. Without considering these additional moments the design might be unsafe.

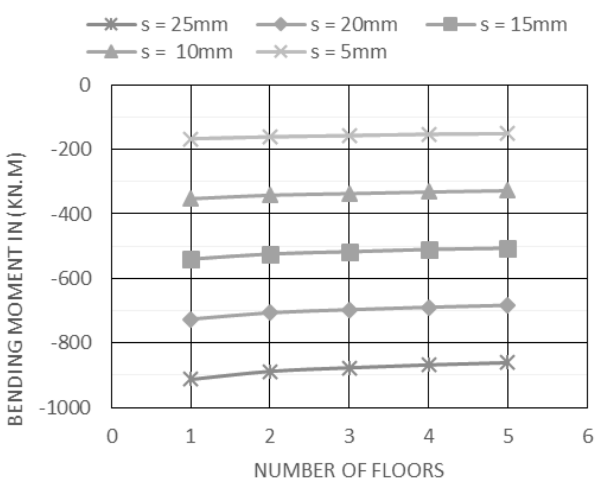

Figure 10. Maximum bending moment at the first span of the lower bay beam for different number of floors for different horizontal and vertical Settlements

6 CONCLUSIONS

This paper studies the effect of the ground movement due to excavation of wastewater disposal well, which is common in Sudan. The study demonstrates the importance of considering the induced movement due to excavation in early design stages to ensure safe design and avoid unpleasant appearance of cracks in walls and partitions. More detailed numerical investigations are recommended considering well-soil-structure interaction. Experimental work on this problem will have a great addition to the knowledge.

7 REFERENCES

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