Bending Stress Response of Strap Beams

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Abstract: ***A strap beam is designed to redistribute the weight of a column between two or more footings. The combination of the footings and the strap beams is known as strap footing. Strap footings are in practice are constructed either with the strap beams at the same level with the footing or at above the footing levels. All these are based on assumptions that the structural behavior of the two strap footings arrangements is the same in either arrangement. This study determined the structural response of strap beams based on physical footing models with two types of connections and compare the results with those from the conventional analysis approach, two assemblies of strap footing arrangements consisting of two RC columns 0.15m x0.15m x 0.6m on 0.5mx0.5mx 0.3m RC bases and connected by RC strap beams of 0.15m width by 0.3m depth by 1.5m length at different levels of connection were constructed and tested in a structural laboratory. The various strains were recorded on application jacking forces through steel I beam horizontally placed on the top of the two columns thus equally distributing the applied axial loads through a centrally placed loading cell. Conventional analysis was undertaken and the values compared with the experimental results. The study revealed that in above the footing level the deviations are between ±36-41% for same level as footing connection case, the deviations are more diverse with no clear pattern. The results for above footing level connection indicates a better agreement with the results of conventional methods with a correlation of 92.5% while for same level as footing has 88.7% correlation.***

Keywords: Strap beam, footings, Bending Stress, Structural Response, Reinforced Concrete

1. Introduction

The foundation is the most important member of the building and a precise analysis of footing will result in more safe and economic design. The superstructure in the conventional design procedure is usually analyzed by isolating it from the soil-foundation medium, assuming that the superstructure is fixed at the foundation level and that no interaction takes place. Such an analysis neglects the flexibility of the foundation and the compressibility of the soil mass. Further the effect of deformations of the foundation on the redistribution of forces in the superstructure is also ignored in the conventional design. Due to the compressibility of the soil medium, foundations undergo horizontal and vertical displacements and rotations. In order to maintain the equilibrium and compatibility between soil, foundation and the frame, the redistribution of forces must take place within the system. A more rational solution of a soil-structure interaction problem can be achieved by appropriate analysis. In any structure, the superstructure and the foundation founded on soil constitute a complete structural system. Neither can be analyzed without considering the other. Previous studies have concentrated on the effectiveness of strap beams in transferring column loads and moments without regard to the strap beam stresses in comparison with the assumptions in the conventional analysis method and connection type.

2. Conventional Analysis of Strap Footing

Analysis and Design of strap footing is based on the assumption that the strap beam connecting the interior and exterior bases is not in contact with the bearing stratum such that soil pressure is not exerted on the beam itself. The strap, assumed to be infinitely stiff, serves to transfer the column loads on the soil with equal and uniform soil pressure under both footings. The means used to provide this pressure relieving effect varies from indicating polystyrene between the beam and the bearing soil to simply show a gap or prescribing a tapering beam. Both footings are proportioned that under service load, the pressure under each of them is uniform and the same under both footing. It is necessary that the centroid of the combined area for the two footings coincide with the resultant of the column loads.

3. Effect of Strap Beam Length and Connection Level

Shallow foundations are designed to satisfy bearing capacity and settlement criteria thus ensuring that the settlement is within tolerable limits. The settlement criteria are more critical than the bearing capacity one in the designs of shallow foundations. [1] Investigated the interlinking between tie beams and footings depth. A finite element package of the PLAXIS version 7.2 (a finite element code for soil and rock analyses) was used for proposal of a two-dimensional finite element model in order to simulate theoretically tie beam and foundations. Settlement was found to be sensitive to the tie beam length connected footings. It was also found that the settlement under footings connected with tie beam decreases with decreasing tie beam length. However, footings connected with short tie beams are found to work as combined footings. The effect of soil flexibility and beam stiffness on contact pressure, settlement and bending moment of strap foundation were presented. The finite difference technique has been used to solve the beam-footings system. The Winkler foundation model was used to represent the soil behavior.

[3] used a finite element package, PLAXIS 3D, 2D version 8.2 to determine the effect of tie beam length and width on settlement under footings as well as the effect of overlap stress on settlement.. Effect of overlap stress on settlement as well as effect of tie beam width and length on settlement was determined. Also, the efficiency of tie beam length and width was obtained using the equation below.

$$\text{Efficiency}(\eta) = \frac{(\text{Settlement without tie beam} - \text{Settlement with tie beam})}{\text{Settlement without tie beam}} \times 100$$

The settlement of footings was also found to decrease with increasing tie beam width. It is found that the settlement after the effect of the overlap stress zone increases with increasing the length of tie beam. [2] investigated the effect of tie beam dimensions (length and height) connecting two isolated footings on the vertical displacement in Y-direction (settlement) and horizontal displacement in both X and Z directions. A finite element package of a PLAXIS 3D version 1.1.3.16 (a finite element code for soil and rock analysis) was used to investigate the behavior of two isolated footings of different dimensions connected with tie beam. It was found that the vertical displacement in Y-direction (settlement) and horizontal displacement in both X and Z directions increases with increasing the length of tie beam. Also, the vertical displacement in Y-direction (settlement) and horizontal displacement in both X and Z directions decreases with increasing the angle of internal friction in sandy soil as well as cohesion in clayey soil. The vertical displacement in Y-direction (settlement) and horizontal in X and Z directions decreases with increasing the height of tie beam. Increasing the depth of footings leads to decreasing the vertical displacement in Y-direction (settlement) as well horizontal in X and Z directions.

[2] investigated cooperation between footings and tie beams to transfer the vertical loads of column to supporting soil. They considered strap beam dimensions (depth and length), vertical position of tie beam (in footings level or above footings surface) and the footing depth as well as soil type with or without upper tie beam as their parameters for centric and eccentric footings investigation. The finite element technique was used to perform the analysis for the problem. Commercial package "COSMOS/M version 2.6" was used. Footings, beams, upper tie beams and columns were modeled using three-dimensional eight–node solid concrete elements. Soil was modeled using one dimensional two nodes linear spring elements.

[4] investigated the Influence of Tie Beams on the Shallow Isolated Eccentric Footing System. He studied the influence of strap beam or tie beam stiffness and allowable bearing capacity of soil in contact pressure, the percentage of column loads transmitted by tie beams, the percentage ratio of vertical displacement to length of tie beam (at edge of eccentric footing, middle of strap beam, centre of interior footing and middle of second tie beam) and the maximum percentage ratio of differential displacement to length of tie beam. Role of tie beam position in the same level of footing and above the surface of footing was also presented. He concluded that Strap and tie beams connected with footings in the same level transmitted the column loads more than that above the surface of footings and also Strap and tie beams in the same level of footings are minimized the vertical displacement of footing than that above the surface of footing.

[5] in his study of heave problem in spread footing in Jordanian expansive soil revealed that the spread footings in the damaged part of the structure are over design, while the grade beam used to connect these footing is under design. The buildings foundation under study consisted a spread foot system with a strap beam. The study revealed that swelling of inner soil zone and the shrink of soil in the perimeter of the building led to a differential settlement which caused the cracks. The case study emphasized the importance of maintaining a reasonably uniform state of subsoil moisture around the buildings. Although the footing designer used a continuous grade footing beam to increase the footing stiffness to encounter differential heave and settlement, the stiffness of the used grade beam was under deigned. This study concluded that the individual spread footings were overdesigned while the tie beams were under designed.

[6] in his research on the design of boundary combined footings of rectangular shape using a new model considering real soil pressure and the classic model taking into account the maximum pressure. The model applies only for design of boundary combined footings, the structural member is assumed to be rigid and the supporting soil layers elastic, which meet expression of the bidirectional bending, i.e., the variation of pressure is linear. He concluded that his proposed model considering real soil pressure presents a more realistic case and better economy in design.

[7] in his study to determine the effect of relieving pressure from the strap beam on the design assumptions found out that when the beam is under no pressure the critical moments and shear forces remain constant irrespective of the beam width. However when the strap beam is not relieved of pressure, the moments and shear forces increases with increase in width of strap beam. In his study he considered a monolithic strap beam constructed in same plane with the base as shown in fig 1.5c and 1.5c.

[8] studied the soil-structure interaction of a plane frame, combined footing soil system, taking into account the elasto-plastic behavior of the soil including strain hardening characteristics. The elasto-plastic behavior with and without strain hardening was examined in their study. The axial forces and moments in the frame and the foundation varied significantly between the methods analysed and are higher for the strain hardening condition. In their next study, [8] discussed elasto-plastic idealization of soil using six different yield criteria in the soil-structure interaction analyses and also compared the results with the results of non-linear analyses. They reported that, in general, the transfer of forces and moments takes place from exterior to interior columns when the soil remains in an elastic state.

[9] examined the influence of column spacing on the behavior of a space frame raft foundation soil system under static loading using ANSYS software. They observed that the settlement increases considerably with increases in column spacing. The column spacings resulted in the rafts of the two raft types, rigid raft and flexible raft according to the bending moment in the raft.

4. Methods and Materials

The model tests were conducted on specimen of two RC strap footing assemblies with strap beam length L, of 1.5m produced using a C25 class of concrete and high yield deformed bars type II reinforcement steel of 460 N/mm^2

conforming to BS4449:2005. One assembly consisted of strap beam at same level as footing while in the second assembly, the beam was placed above the footing surface. The assembly layouts and reinforcement detailing are as shown in figure 2 and figure 3.

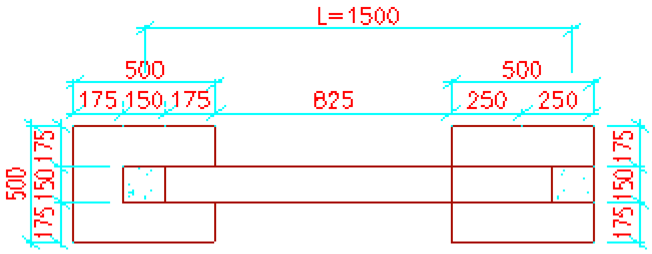

Figure 1: Assembly layouts

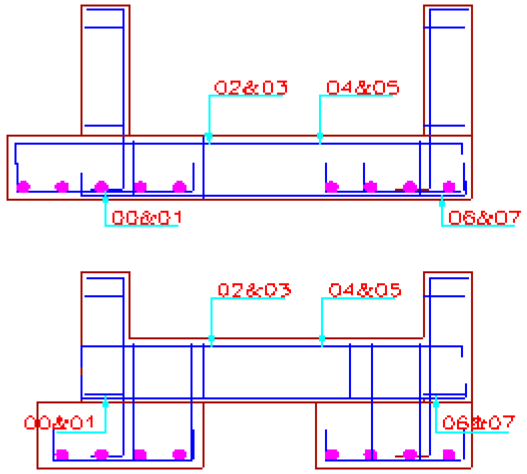

Figure 2 Reinforcement detailing

5. Results and Discussions

The stresses at equivalent strap beam locations from the conventional analysis method were compared with the experimental results. The graphs (figures 3 to 6) indicate existence of variations in the developed stresses due to the two connection types. In both the experimental results and the conventional analysis results, it is indicated that maximum bending stresses are developed at equivalent strain gauge position 04&05. The stresses developed on the strap beam with above footing connection are the least in all the cases. It is shown that the same level connection develops larger stresses than envisaged in the conventional method. Minimum stresses are experienced at equivalent gauge location (06&07).

The results further indicate that the strap footing stresses in the conventional analysis at the equivalent gauge positions 00&01, 04&05 and 06&07 are more than in the above footing level by an almost constant factor of 34%-41%. In the case of the same level with the footing connection at similar gauge positions, there exists a huge variance in the stress deviations with a minimum of -44.7% at 06&07 and maximum of 29% at 00&01as opposed to the first scenario. This is attributed to the diminished influence of ground pressure on the strap beam in the case of above footing connection. The beam therefore purely transfers eccentric loads to the centric column. In the case of the same level connection, the higher stresses are experienced due to the additional influence of ground pressure. The beam therefore transfers the eccentric column loads and resists the ground pressure thus experiencing higher stresses.

In all the cases the deviations are amplified at equivalent gauge locations 02&03 with 83% and 73% for above the footing level and same level as footing connections respectively. At this location, though the experienced stresses are smaller, there exists the highest variance between the between the experimental results and the conventional results. This shows that there is significant under estimation of stresses in the conventional method at this location. This location is an interface between the centric base and the strap beam and therefore the beams and the base tend to operate as one unit in practice. The conventional analytical method does not consider this hence the difference. However, the insignificantly smaller stresses at this location do not affect the design consideration of a strap beam.

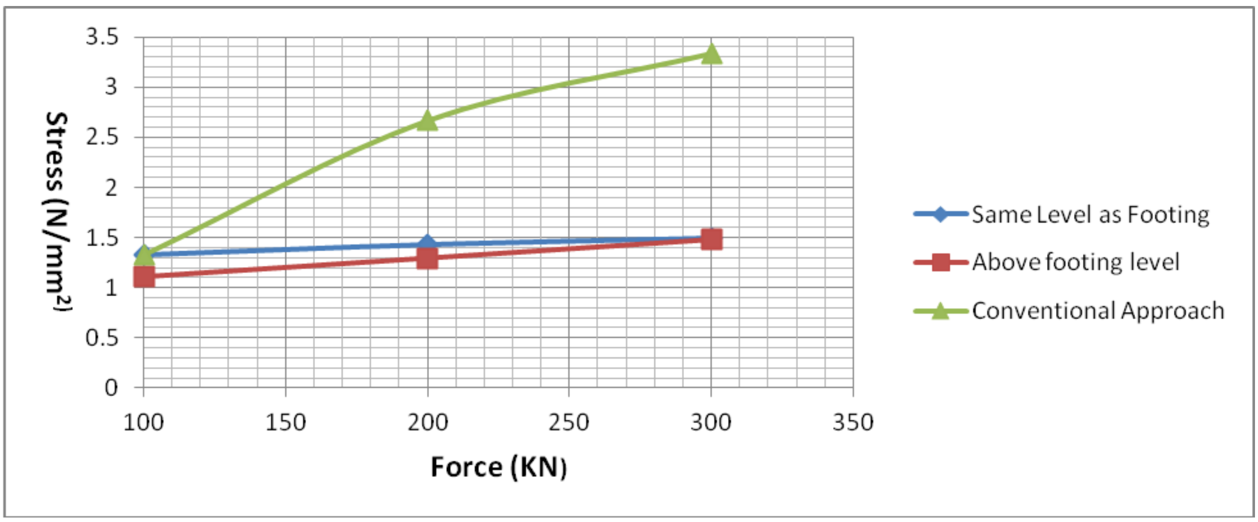

Figure 3: Bending stress vs Force - gauge position 00&01

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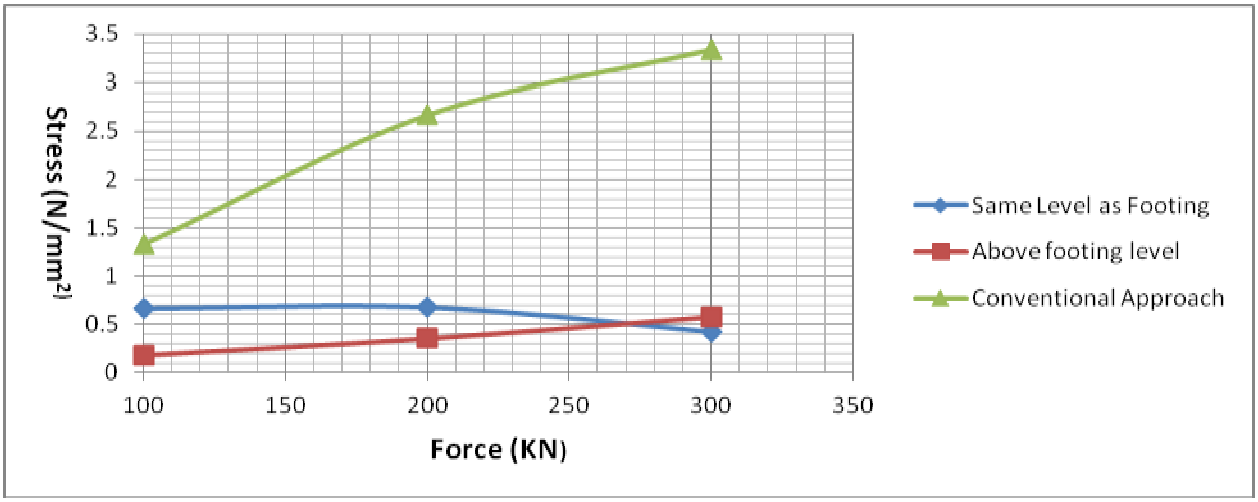

Figure 4: Bending stress vs Force - gauge position 02&03

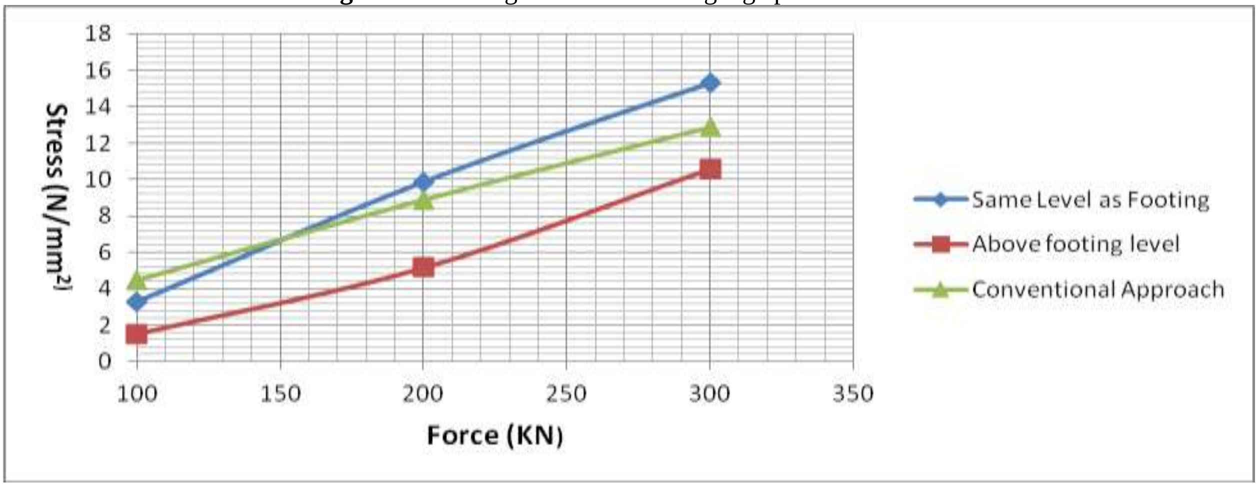

Figure 5: Bending stress vs Force - gauge position 04&05

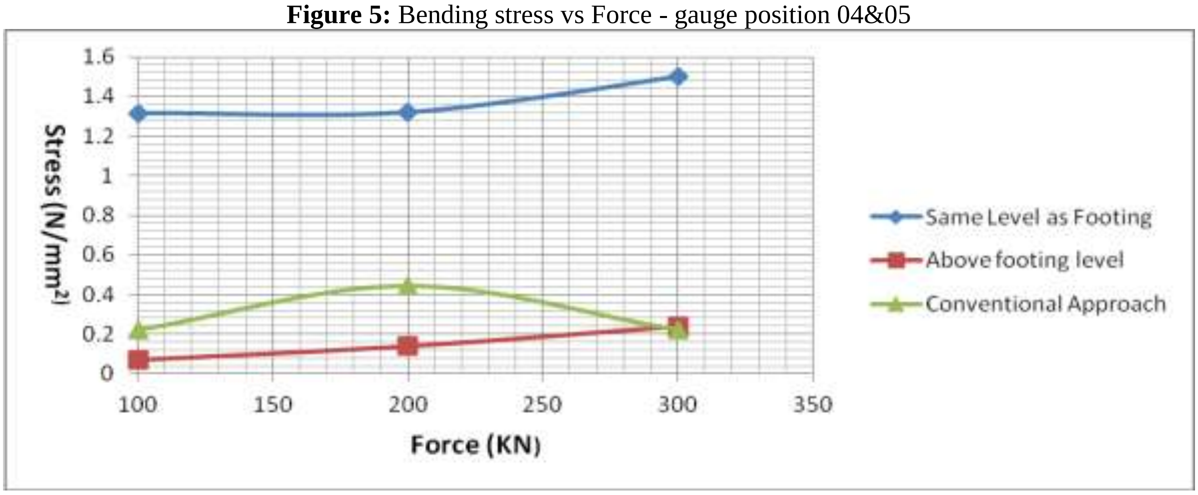

Figure 6: Bending stress vs Force - gauge position 06&07

6. Conclusion

Within the range of parameters studied and the test results, a comparison between the strap beams stresses obtained from the conventional analysis method and those obtained from experiment the following conclusions are deduced:

- In above the footing level the deviations are between ±36-41%; except in gauge position 02&03 where the deviation is about 83%.
- For same level as footing connection case, the deviations are more diverse with no clear pattern. 26% at gauge positions 00&01, 73% at 02&03,-2.6% at 04&05 and -447% at 06&07.
- The results for above footing level connection indicates a better agreement with the results of conventional methods with a correlation of 92.5% while for same level as footing has 88.7% correlation.

The future research work should therefore address the below mentioned points:

- Incorporate SSI modeling to achieve more realistic ground modeling and response of strap footings and subsequently safe and economical foundation.

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- The present work can be extended to different strap beam lengths, footing depths and soil properties.

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