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FEM Based Study on Optimum Design of Geometry for RC Rectangular Silo Bearing Extreme Asymmetrical Static Loads

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Keywords

Rectangular RC Silo,
RC Shell,
Optimum Design of Silo,
Asymmetrical Loading,
Geometrical Optimization,

Abstract

Special reinforced concrete structures using has become common in several industries. RC silos, storage, and maintenance of fine grains in industrial units that are a complicated structure in designing could be obvious illustrations. Therefore, getting the optimal design with the required strength is one of the most important issues should be considered in this type of structure. In this study, by reviewing six different FEM based simulated models for designing a rectangular concrete silo under static loading, we have tried to show a numerical study on an optimum geometry plan for silos bearing extreme asymmetrical loads. The dimensions indicated in the same range for all specimens and with a clear algorithm; In the final stage, all of the results have been compared and examined. Reviews provide some results that can be helpful in planning a silo structure with the same condition by designers. The optimal design model will provide an ultimate design, which is optimistic and economic as well.

1. Introduction

Generally, reinforced concrete shell structures for silos may design and executed in two different types: with RC frame and with RC shells only. Concrete rectangular silos, like other important structures, must also be able to withstand lateral loads, including earthquakes, in addition to gravity loads, which, in fact, unloading and loading (filling) with forces of varying amounts and directions. These forces will be formed by moments, axial and shear reactions as well as torsion in the shells. The elements must be controlled for each of these reactions and designed for the most critical situation. In this research, a rectangular silo has tested in six different models by integrated solution program. The purpose of this research is to achieve an optimistic design of silo structure for storage silica material with weight per unite of 1.75 (t/m3) that will meet all aspects and needs for considered structure and similar cases too.

2. Computer Based Modeling Experiments and Studies Samples

As mentioned in the preamble, this research has done on six different models of rectangular concrete silos. In the first stage, the silo was examined in two different plans, one with a vertical internal concrete wall only (Figure 1) as well the other with a horizontal internal wall (Figure 2). The modeling and analysis carried out using Finite Element Modeling programs. Loading conditions indicated according to the material characteristics. According to the studying aims loading and unloading the material were considerable loading cases in analysis. In fact, static asymmetrical loads were from stored material. The performance of the structure reviewed for all reactions. These results for internal forces of the members were worthy to consider as two vital factors of shear reactions and bending moments. In this study, equivalent static analysis is used to examine the performance of the structure.

2.1. Case I

In this model, a vertical middle concrete wall in the longitudinal direction of the structure has shown (Figure 1). The shear force (Figure 3a), and the bending moment, (Figure 3b) at the outer wall and internal walls, represent the maximum and minimum value for the foundation. This is evident throughout the length of the walls. By examining other load combinations and loading patterns, it observed that in both cases, the tensile and compressive loads did not change significantly, and the points of connection of the shells was considered as critical point. Since the wall is laid in a longitudinal direction the structure does not have sufficient flexural rigidity in this direction. This can be easily understood by examining the bending moment values and even shear forces. This problem can be resolved by increasing the thickness of the walls at these points and in some cases by increasing the amount of steel to a certain extent. However, in the boundary elements between the two

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perpendicular walls cracks and the progressive deflection of concrete increases with gradual increase of loads, and it is necessary to think for these boundary points. This problem can be offset by increasing the shear reinforcement steel, but this can be effective as long as the cross section is not over stressed in terms of steel. Sometimes forces from filling in case of non-symmetrical loading and this may cause of the bending to occur in the inner region of the inner wall and causes an overturning moment in the structure.

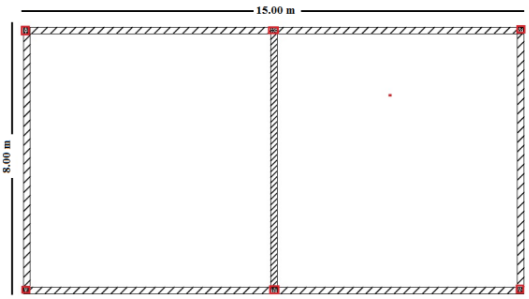

Figure 1. First model with one vertical wall only

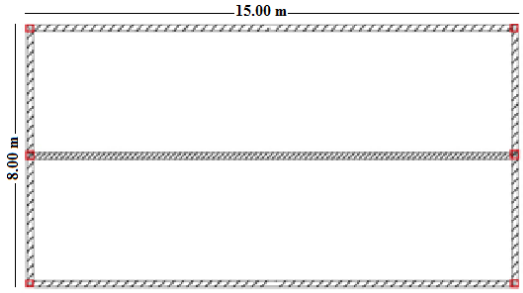

Figure 2. Second studying model with one horizontal wall only

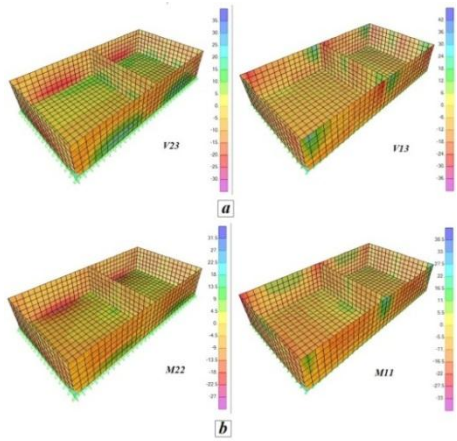

Figure 3. (a) Shear Force results in silo shells at two directions. (b) Moment results in silo shells at two directions

2.2. Case II

In this model (Figure 2), a horizontal concrete wall added in the middle. The shear force (Figure 4a) and the bending moment (Figure 4b) both display the maximum value at the connection area of the inner and middle walls to the foundation. This is evident throughout the longitudinal exterior walls too. However, in the inner wall, the magnitude of the reactions is far apart from allowable maximum amounts. By studying the behavior of the structure, which is similar to the structure reviewed before (Figure 1) on critical loads combinations.

In both cases, the tensile and compressive loads in the points of jointing of the crust with each other at the end points, namely, in the boundary elements of the two concrete shells, bend the moments to the maximum values. In this example, non-symmetric loading, the compressive force resulting from the filling during loading only one of the sources, creates considerable amount of moment due to bending in the middle area of the interior wall and it creates an overturned moment in the structure.

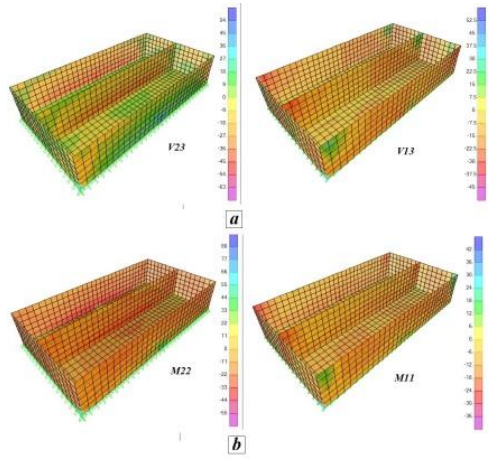

Figure 4. (a) Shear Force results in silo shells at two directions. (b) Moment results in silo shells at two directions

2.3. Case III

In the third case investigated model analyzed with two vertical walls, which are transverse to the structure and in the middle (Figure 5). In this model, the structure had three reservoirs. Although the structural rigidity increases with the addition of another wall to the previous model (Figures 1 and 2). However, by studying the results of shear force analysis (Figure 6a) and bending moment (Figure 6b) the maximum value can be observed at the connection area of walls to the foundation. Although these walls were the main bearing members of the structures, the sidewalls were not in critical condition like them.

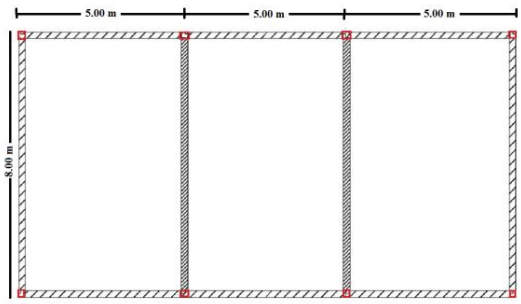

Figure 5. Third model with two vertical walls

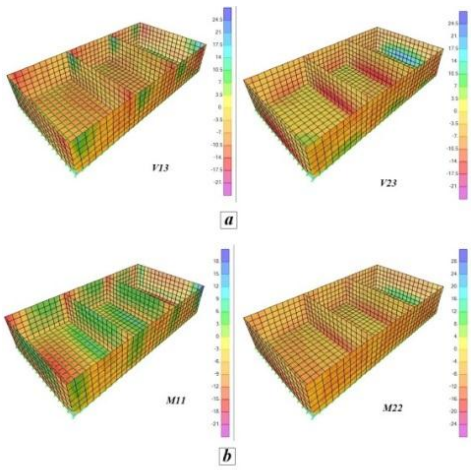

Figure 6. (a) Shear Force results in silo shells at two directions. (b) Moment results in silo shells at two directions

It was clear that the inner walls have a larger share stress after affected by material filling loads. When loading was asymmetric, the pressure from the filling, during loading on the one or several alternative sources, increased the shear stresses in the internal walls and the bending moment resulting from an asymmetric loading in the entire structure. Comparing the results of the analysis of this model (Figure 6) with the previous model (Figure 4) there is no significant difference in the optimum designing achievements. Nevertheless, the division of the loading area from two sources to three sources, in the case of asymmetric loading, bending moment in the elements will make a little deference between two previous models but rigidity of the structure increased significantly.

Compared to model (Figure 7) although the RC frame system was added into an integrated system, the structure's rigidity increased somewhat. However, cannot be ignored the focus of the shear stress in the borderline elements of the wall and the columns in the middle of the inner walls, see Figure 8. The phenomenon might was attributed to the absorption and control of displacement by the column-wall system. At the intersection area of the columns with shell, there were obvious stress concentration because of difference between stiffness of the elements (Figure 8). As well, the boundary elements of the shells at this area, become rather stiff along with cracks with small width, see Figure 9. These cracks occur in concrete shells too. As a result, the critical issue was joining points of columns and shells.

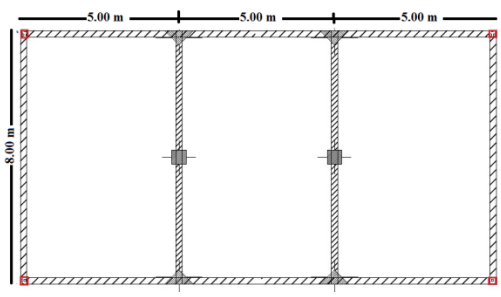

Figure 7. Fourth model with two vertical wall supported by columns

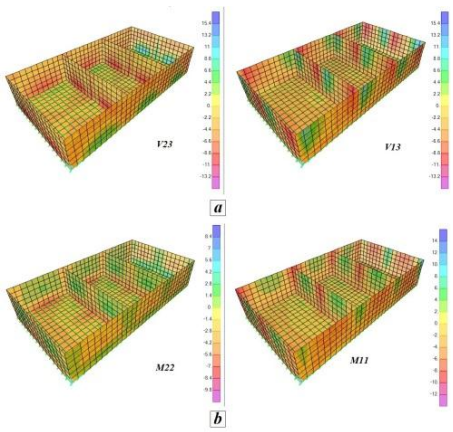

Figure 8. (a) Shear Force results in silo shells at two directions. (b) Moment results in silo shells at two directions

2.4. Case V

In this model (Figure 10), the system was analyzed with considerable rigidity by removing all the columns from the model of (Figure 7) and adding a wall of concrete, longitudinal and crosswise with two existing walls. In fact, that model was combination of models (Figures 2 and 7).

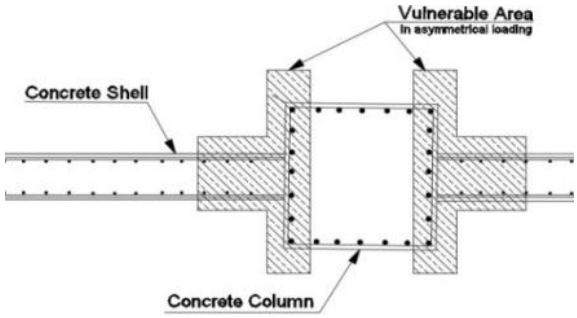

Figure 9. Vulnerable zone due to asymmetric loading in the middle of interior shells supported by column

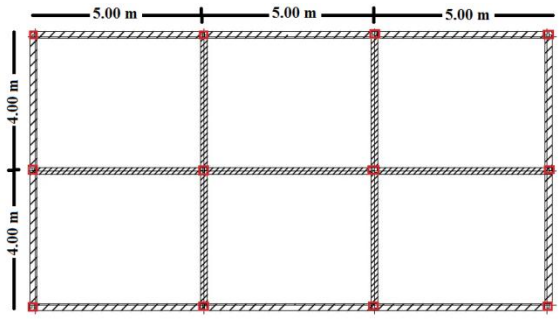

Figure 10. Fifth model with two vertical and one horizontal walls

It was undeniable that the values of displacement and deflections do not exceed the permitted values. The axial stresses in the shells did not exceed the strength of the concrete. By observing the results of the shear force analysis (Figure 11a) and the bending moment (Figure 11b) at the external walls and the inner walls to the foundation, as well as at the interface between the horizontal and vertical walls, the values of shear stresses and bending moments to the average limit value reached. However, the system was not over-stressed but the shear stresses in the connection area of external walls with foundation in the range of (0.14h) silo height are close to maximum values and structural behavior

was in the elastic range. In this model, asymmetrical material loading are done on several sources with less volume in compare with previous sources then deformation in the walls are increased. It was clear that because of obtaining an acceptable range of reactions the thickness and reinforcement of the walls could calculate until resulting an optimum design.

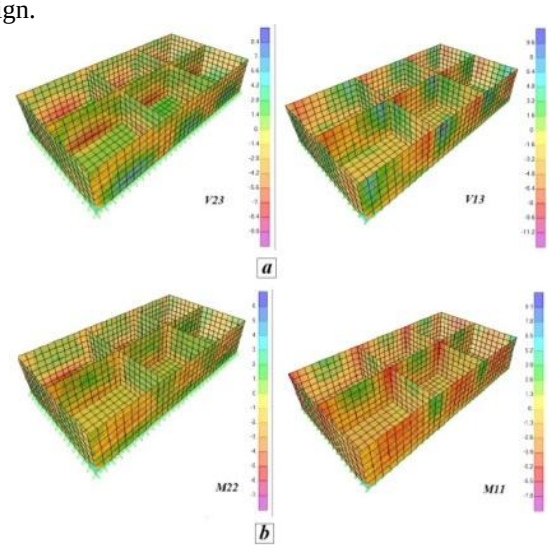

Figure 11. (a) Shear Force results in silo shells at two directions. (b) Moment results in silo shells at two directions

2.5. Case VI

In the fifth case, the last, sixth, model (Figure 12) was reviewed in addition to the plan similarity to fourth case`s model, see Figure 10. location of the joints of the shells has been designed with concrete columns with compatibility of section installation angle and the walls intersection areas. The effect of the adding these columns with geometry properties shown in the model (Figure 12) was available as FEM results, see Figure 13. The results of shear force analysis (Figure 13a) and bending moment (Figure 13b) at the joints site indicate significant changes in the amount of reactions. Stiffness, stability and structural strength of this system approached to maximum values.

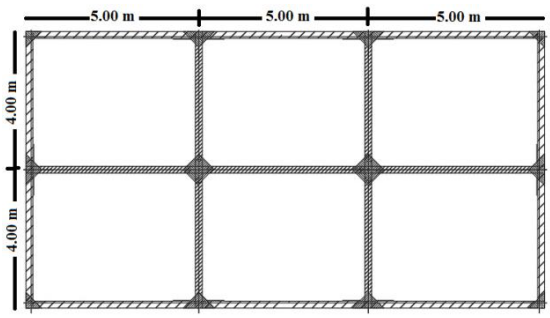

Figure 12. Sixth model with vertical and horizontal walls supported by columns in the junction points

The reason for the addition of concrete columns at the intersection of internal shells was to control the significant amount of shear reactions in the boundary elements, see Figure 9. By comparing, the values obtained from the analysis of this model with previous-five models (Figures 1, 2, 5, 17, and 10), these changes were very appreciable. In this model (Figure 12), structure performance should be judged as an integrated-framed shell structure. However, for obtaining a better-optimized model, the cost of construction will exceed the previous case (Figure 12) if the additional tensions are compensated by increasing the wall thickness, then insertion of these columns will be more economical. The behavior of the sections of the structure will be approximately within the elastic range.

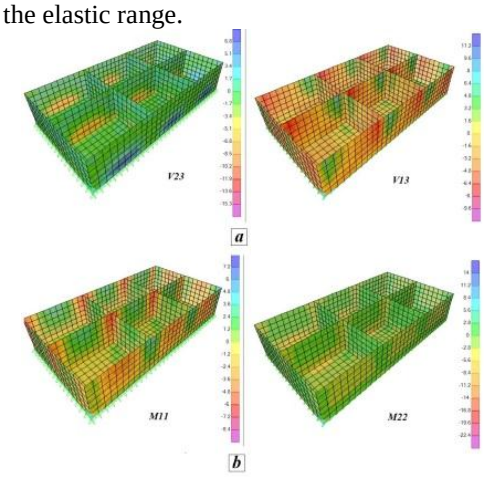

Figure 13. (a) Shear force results in silo shells at two directions. (b) Moment results in silo shells at two directions

3. Analytical Observations and Discussion

In the previous section by examining six models and review the graphical output of FEM modeling, necessitate of doing more study on seismic behavior of models is admitted. As they are investigated in similar conditions and the results are analyzed by the program outputs, geometrical evaluation of this study says that the cross point of shells is considered to be critical points and the behavior of these points in each model has a variable range as shown in (Figure 14). In the models where the shell was crossed without columns, the behavioral range of the structure went up to the plastic range and the cracks grow with increasing the loads. The structural performance of the boundary elements should be improved either by increasing the shell's dimensions. It can be closer to the elastic one or with increasing stiffness and energy absorption, this range could be provided. However, what is at stake in these studies is the use of concrete columns at these critical points. In addition to achieving a well-designed calculation, it is possible to improve other structural features in these areas. In fact, the model with concrete columns at the joining points of the shells (Figure 12) and the model without concrete columns in these areas (Figure 10) are important points of this study.

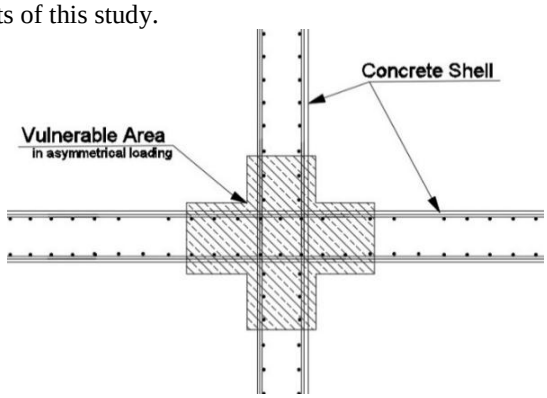

Figure 14. Vulnerable Area due to asymmetric loading in the point of junction of two interior shells

To strengthen this issue, it was a curt study on retrofitting and rehabilitation of three existing silica storage rectangular silos, see Figure 15. The structures reviewed by author were located in the Istanbul province. The samples were three rectangular concrete silos with a length of 45 meters and a width of 8.5 meters with a similar plan to the model of (Figure 15) with an average age of 27 years as shown in, see Figure 16. According to the related figures, silos with a height of 15.2 m (Figure 15a) are located on a base floor at a height of 3.2 m (Figure 15b). The plan of these silos was in accordance with the model of fifth case, of this study see Figure 12. In the initial modeling of these silos, and with the removal of existing structures including concrete strength, the existing forces from the materials were applied to the structures according to the information provided by the employer and the company owner of the silos. These silos needed retrofitting and repair and some of their elements were failure or spoiled significantly. These structures were analyzed using non-linear analysis. The results of the analysis indicated that none of these three silos provided the life safety (LS) level. Structures at the connecting points of the shells under asymmetric loading (Figure 17) were subjected to shear stresses and bending moment at maximum at the points of the shell joints and the structure has suffered minor damage in some of these areas. The adverse environmental conditions (coastal with high salt concentration) are also one of the reasons for the destruction of these structures (Figure 16).

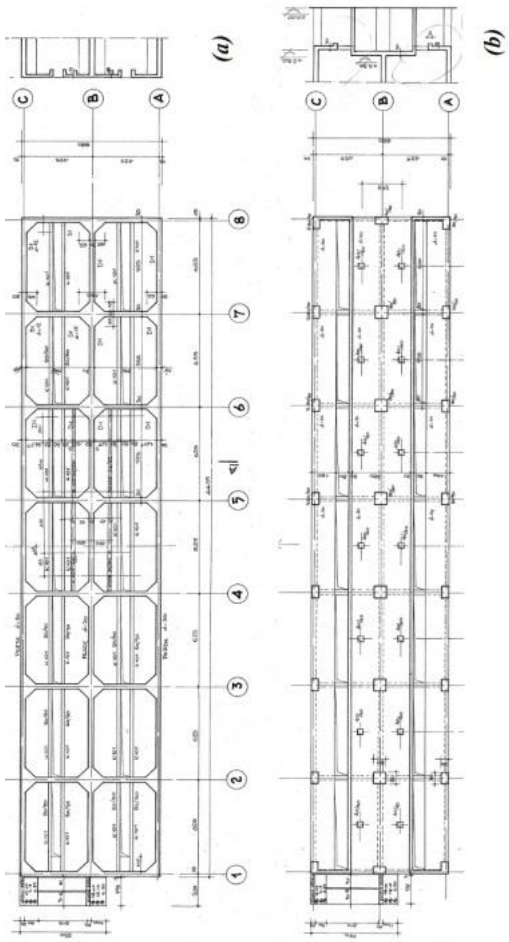

Figure 15. Studied concrete rectangular silos plan and sections (a) base level (b) up to +3.2m

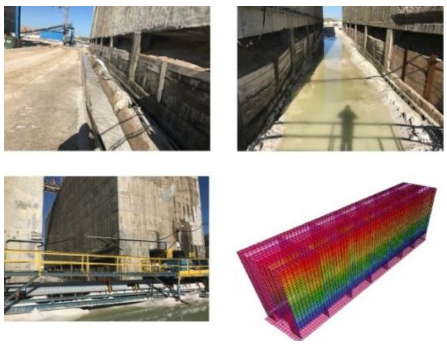

Figure 16. Studied concrete rectangular silos conditions and FEMA model 3D view

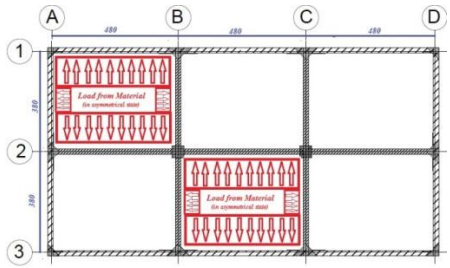

Figure 17. Studied concrete rectangular silos asymmetrical loading schema

The values of lateral deformations of this structure at the shells, as well as in the concrete flexural frame, exceeded the permissible values in some points. This was not mean that the structure was designed weak for related loads, but atmospheric and environmental factors as well as the age of concrete structures were important factors in determining the level of performance and structure response. The important point is that the actual test specimens are related to the samples tested in this program that the structures under the rigorization operations had the same plan as the test sample plot (Figure 12). In the analysis of these experimental models, the realistic loading modes (Figure 17) were used as one the important loading combinations for retrofitting. This work was done to investigate the claims of this article. By examining the results of the analysis of each of the models, the models with plan (Figures 1, 2, 5 and 7) failed to satisfy the expectations of the structural performance under same condition, and the shell elements alone could not withstand the loads. The continuation of the design process with these plans for this type of loading was virtually economical, and not even technical. However, the model (Figure 10) was able to withstand, in part, the accepted performance of the load.

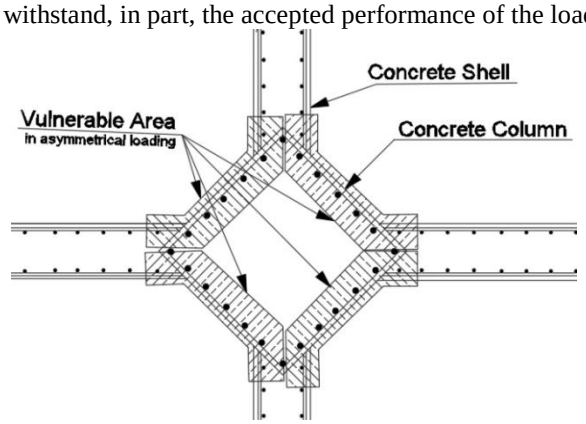

Figure 18. Vulnerable Area due to increase of extreme asymmetric loading in the point of junction of two interior shells supported by concrete column

However, for the load combinations carried out tensile stresses along with live load (material filling load inside silo) there was no acceptable resistance in the element. Calculation process continued on fifth model of study too. The loading with realistic loading taken from existing silos, see Figure 15 and 10. But the final design was resulted with larger sections and the high amount of thickness of the concrete walls. On the other hand, by examining the existing structures (Figure 15) similar to the plan (Figure 10) the sections were much closer to the existing structures. However, its structural performance was desirable and close to the performance of the existing structure. The existence of a height of 3.2 meters (Figure 15b) shows a different response from the structure for lateral forces too. In fact, it can be stated that this kind of model may be the best plan for this assumption of silos bearing asymmetric loading conditions in compare with the other five models presented in this article. One of the other specialists of this plan is using the square section column in shells connection point angled about 45^0 (Figure 18). It is shown from the analysis; that this point may be critical and vulnerable area in structures with, see Figure 12. plan but according to analytical reports for several models studied on reducing vulnerability and obtaining optimum connection, use of angular concrete column (Figure 18) will show suitable performance in comparison with connection investigated in this article models (Figure 9).

4. Conclusions

In the percent study, the authors investigated the effectiveness of architectural planning of rectangular silos in obtaining an optimum design satisfied with all structural principles and good response of seismic behavior. A careful interpretation of the experimental and analytical results leads to more specific conclusions are presented in rather a qualitative manner as follows:

4.1. Rectangular RC silos, included RC shell walls partitions in only horizontal or vertical direction (Figures 1 and 2) did not satisfy strength designing criteria under asymmetric loading.

4.2. Adding other walls for reducing the reaction amounts in structure (Figures 1 and 2) could be effective in some aspects such as shear stresses in walls but connection joints are the critical and also vulnerable points.

4.3. Silos with RC shell partitions in the both horizontal and vertical directions (Figure 10) could show acceptable performance in extreme asymmetrical material filling loads but in the same view for silos with walls in only one direction, walls junction areas are vulnerable for shear stresses.

4.4. The shear reactions in the joint areas of silos with RC shell walls in two directions generally have suitable performance in loading symmetrically. But, during analysis with asymmetrical loading, it could be seen overs stressed conditions in walls junction areas (Figure 13) are more probable with asymmetrical material loading.

4.5. Rectangular RC silos in that the connection joint areas of partition walls are supported by columns (Figure 12) showed highly performance during loading in the same conditions like other models. Walls joints and the wall-column connection area`s reaction amounts are about 20% below of the allowable amount limits but elements are not in a vulnerable conditions until increasing asymmetrical filling loads.

4.6. These kind of plans for designing of RC rectangular silos are not involved in weak connection area problems (Figure 17) in the normal service using but in the special loading conditions like asymmetrical filling load (Figure 14) along with earthquake seismic loads, it could be expected that primary cracks that can be seen in the vulnerable junction area.

4.7. Among the common plans for designing of RC rectangular silos with interior walls, the model (Figure 12) could be optimum choose according to the extreme loading conditions that are studied in this article. This issue has been proved by presenting study results on three existing silos planed in same geometry.

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