# STRUCTURAL INTEGRITY REPORT -FINAL

GTMC WAREHOUSE -CHEMICO PROJECT

Finding the cause of failure and recommendations for restoration

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**18/04/2012**

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**GTMC WAREHOUSE - CHEMICO PROJECT**

**TEMA**

**18TH APRIL, 2012**

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## 0.0 EXECUTIVE SUMMARY

The client has invited Ing. Allotey to assess causes of structural failure of his warehouses in Tema, used basically for the storage of fertilizer components, and to come out with interim and long term measures to remedy the situation.

The methodology applied in the assessment was:

1. Visual assessment of failures and structural behaviour of the various structural members of the building
2. Structural redesign of the whole or main elements of the structure and comparison with the initial design from the structural engineer
3. Material test on the various structural members of the building and soil (where necessary) , and comparison with the design specifications

Based on the above methods applied, the state of the materials and structures of the building were able to be estimated. The following main summary observations were made:

1. As at the time of compiling this report, no structural or architectural drawings have been made available to me.
2. However, it was realised that, some portions of the main warehouse walls have collapsed, while almost all the other walls have indicated macro cracks( about 1 to 5mm width), a distance of about 1/3 the height of fill of the fertilizer. Same could be said of adjoining columns to those walls mentioned.
3. Various tests are yet to be conducted to ascertain the quality of materials used in the construction. Among these are concrete compression test for columns and beams, compression test for masonry blocks and geotechnical test of the soil.
4. The above observations suggest strongly that, the total collapse of some of the walls, the excessive cracks and deflections and buckling of most of the structures in its loaded state, makes the structure very much unsafe for human life

Based on the above observations, it is very much recommended that:

1. For a short term or immediate solution, a retaining wall be constructed to the height of the middle beam (about 6m from the finished floor level) to retain the material against lateral load

2. However for a long term solution, the whole structure be pulled down and reconstructed.

## 1.0 Introduction

The presence of excessive cracks and obvious deflection in the warehouse structures, coupled with the eventual collapse of some walls of the warehouses, called for the assessment of the integrity of the whole structure.

The client wants to know the cause of the structural failure and then have recommendations as to how the problem would be remedied both in the short and the long term.

## 2.0 Methodology

The whole exercise was divided into two sections. The first was to consider the warehouse that has already failed and collapsed. The second section was to consider those warehouses that have shown signs of failures, but are still being used for storage.

To begin the tasks above, extensive visual inspection of the whole structure, to assess the visible failures on the structure, was carried out. The various failures on the structures were captured with a digital camera and also noted down.

From observations and measurements taken from the site, the various structural components of the warehouse were redesigned as existing. It must be noted that, the various warehouses are of similar type in structural system.

Various tests were conducted on Monday the 16$^{th}$ April 2012 to further confirm the cause of the failure of the structures. These test include, compression test of the used concrete in the columns, the strength of masonry blocks used, and geotechnical tests. Reports from these tests are made available at the end of this report under the Appendices.

## 3.0 Observations

3.1 Physical observations

From the physical inspection carried out, the following were realised:

1. As may be seen from the pictures attached the back wall of one of the main warehouses has totally failed and collapsed. The wall took away with it, both horizontal and vertical stiffeners that were supposed to have strengthened it. (fig. 1 and 2)

2. It was also observed that the roof trusses were fixed into the upper part of the vertical stiffeners, welded to some of the steel reinforcements of the columns stiffeners. So as the wall gave way and pulled the vertical stiffeners with them, the stiffeners took away also the roof that has been fixed in them.(fig. 3 and 4)

3. It is also very much to be noted that the roof was supported only in one axis. Perpendicular to the said axis, the roof structure was not supported at all.

4. Just from observations, it seems that the timber used for the purling are not of the hard-wood type.

5. The masonry blocks used for the greater part of the wall are hollow in nature and measured maximum 5 inches in width

6. It is also to note that, the vertical stiffeners to the wall were about 4.5m apart from the other. The horizontal ones are similar distances apart. This brings to a bay dimension of 4.5m x 4.5m of masonry wall, used to retain granular material, and piled over 7m high.

7. All other warehouses that are still standing have very significant horizontal cracks about half the height of the lower panel of masonry walls of the warehouse. This is coupled with very obvious deflections, buckling, and sometimes crushed appearance of the stiffeners about along the same line of horizontal cracks.

8. There was no obvious appearance of settlement of any part of the structure. Shear cracks were not seen, and hardly was there any vertical cracks observed.

9. Also observed with interest was the height of the fence wall without a horizontal stiffener. The wall was about 6 meter high. The vertical stiffeners were, from point of view during inspection, were the same width as the masonry blocks, and are about 3m apart. However this fence-wall seems to have been constructed with solid 6inch sandcrete blocks.

10. The water table in the area seems high. This in effect could damp the walls, floor and eventually the loose materials in the warehouse.

3.2 Observation after redesign

Redesigning of the lower panel of the warehouse wall, as it is, showed that there was no way that the masonry wall could retain the material, even if the pile of material were 6m high and has a piling angle of $45^{o}$ to the horizontal. In designing, the masonry blocks and concrete stiffeners were assumed of a high strength ($7N/mm^2$ for the masonry blocks and $25N/mm^2$ for the reinforced concrete columns). This actually was not the case as can be seen from the investigation reports in Appendices A and B. See attached for the design calculation in appendix C

3.2 Observations from various tests conducted

The overall average compression strength of ten (10) columns tested in 3 of the warehouses came to barely $22.16N/mm^2$. The maximum was $29.9N/mm^2$ , whiles the minimum was $16.2N/mm^2$. The minimum structural concrete is $25N/mm^2$. Compare Apendix A. Therefore although some of the concrete strength is found to be within the acceptable strength, the range of strength, being $13.7N/mm^2$ suggest strongly inconsistent batching and quality control/assurance procedures during construction. Appendix B

It was also noted that the blocks used had an average strength of $4.61N/mm^2$. Although this value is above the minimum required, it is way below what was used to redesign (namely $7N/mm^2$). The width of the blocks was also found to be 120mm, less than the 5inch (127mm) assumed for the redesign investigation.

**4.0 Deductions**

As shown by the redesigned calculation, the masonry wall was not able to withstand the lateral load from the loose fertilizer piled up in the warehouse.

The pile of loose fertilizer, at that height, exerted enormous lateral pressure on the 5inch thick masonry wall that was too much for the masonry wall to resist. The fact that there were

reinforced concrete stiffeners in the wall does not provide the guarantee for the wall to resist the in-plane moment resulted from the lateral load of the loose granular material. It must be noted that, the stiffeners themselves were about 6m apart, both vertically and horizontally. This distance is much above that allowed by the code of practise, even for a free standing masonry wall, without lateral load.

It is therefore totally wrong to use a masonry wall to retain a granular material, piled to such a height and in that magnitude.

Another factor could be the high water table that might have dampened the loose granular material, and may have increase the load against the weak masonry wall.

**5.0 Conclusion**

A structure of masonry wall with bay size of 4.5m x 4.5m, with hollow blocks of 5inches thickness as existed in this project will not be able to resist a lateral load coming from a pile of loose granular material, exerting a pressure of about 3.9 to 10 KN/$m^2$. As the code of practise for free standing walls, the stiffener centres are about 3m to 3.5m. This is taken from the BS5628. If the maximum slenderness is 27, then with a wall thickness of about 127mm (5inches), the maximum height of the wall is to be 3429mm (about 3.5m). Therefore the failure and eventual collapse of the warehouse wall may very much have been caused by the lateral pressure of the loose granular material in the warehouse. This is because the stresses due to the in-plane horizontal and vertical moments exceeded the strength of the mortar joints that is the weakest link in the masonry wall. Also in the first place, the slenderness ratio was exceeded. Hence the failure and eventually the collapse of the walls.

The main structural members, namely the stiffeners and beams were also inadequately constructed in terms of the strength of concrete and amount of reinforcement, considering the fact that they ultimately carry the lateral loads on the wall, and not the masonry walls. See fig. 7

It must be noted that, the cracks and deflections as indicated on the other warehouses, are signs of the same eventuality as the first warehouse. They will definitely fail and collapse. See Fig. 5 and 6

The above explanations show that the continuous use of the warehouses would be very dangerous to human life in general.

## 6.0 Recommendation

As requested by the client, it is hereby **recommended** that

1. Immediate and interim measure be taken to remedy the problem
2. And a permanent and long term solution is also to be found

We therefore make the following recommendations as to the point 1 and 2 above.

### 6.1 Interim remedy

For a short term measure, retaining walls are to be constructed within the confines of the warehouse which has to be cleared of all fertiliser material. This retaining wall could be constructed to a height of about 6m high (the height of the middle beam). In doing this it must be noted that, this measure is serving as a support for a permanent measure of remedy.

It is therefore recommended, that the retaining wall should be structurally adequately designed for the final use for the storage of fertilizer in the warehouse. That is to say, the following must be observed:

1. The anchorage depth of the retaining wall must be adequate
2. The wall thickness should be adequate
3. The reinforcement should be enough to retain fertilizer of full capacity of the warehouse
4. Provision should be made for continuation columns at the end of the 6m (top of the wall) at 3m centres
5. The retaining wall and the existing weak masonry wall should be separated with a 20mm thick polysterol material, before the concrete of the retaining wall is cast.

In this situation the warehouse could be used with care for a short time before the final and long term mitigation method is instituted.

6.2 Long term (permanent) remedy - I

Just before the commencement of the second phase to permanent remedy of the situation, the weak old masonry wall outside the retaining wall will be demolished. The polysterol material will make it possible, since it will form a partition between the old weak wall and the new REINFORCED Concrete wall.

The columns provisions made on the walls will now be raised to roof level. Since the lateral load from the loose fertilizer is focused at about 1/3 of the total height (within the lower 4.5 m of the wall), the 3m centres columns, tired with horizontal stiffeners at heights of 2.25m, and in-filled with solid masonry blocks, will be able to resist all loads from the materials in the warehouse and will be more cost effective, than if the reinforced retaining wall is raised to the ceiling level. FIG. 8

At the roof level, the final horizontal stiffener will be used as support for the roof trusses.

It would be very prudent if a maintenance engineer is engaged to manage the facility for the long term.

6.3 Long term (permanent) remedy – II

The second long term solution is the radical way, in which the existing warehouses will be totally demolished in stages and reconstructed accordingly. In this case, one or two of the warehouses will be emptied and the whole structure be demolished, cleaned up and reconstructed with reinforced concrete walls as described under chapter 6.2

Fig. 1

Collapsed masonry wall within the structure of the warehouse

Fig.2

At the back of the warehouse, where failed beams and columns indicates lack of integrity of those structures

Fig.3

Failed upper part of the warehouse wall

Fig.4

Failed roof. Roof now being supported by material in warehouse

Fig. 5

Buckled and ‘crushed’ column

Fig.6 : A typical view of failed masonry works, showing horizontal cracks due to vertical bending of wall. This happens about 1/3 the height of all warehouse walls

Fig. 7 Hanging failed beams and failed columns, indicating that the reinforced concrete members were also inadequately constructed to resist load present

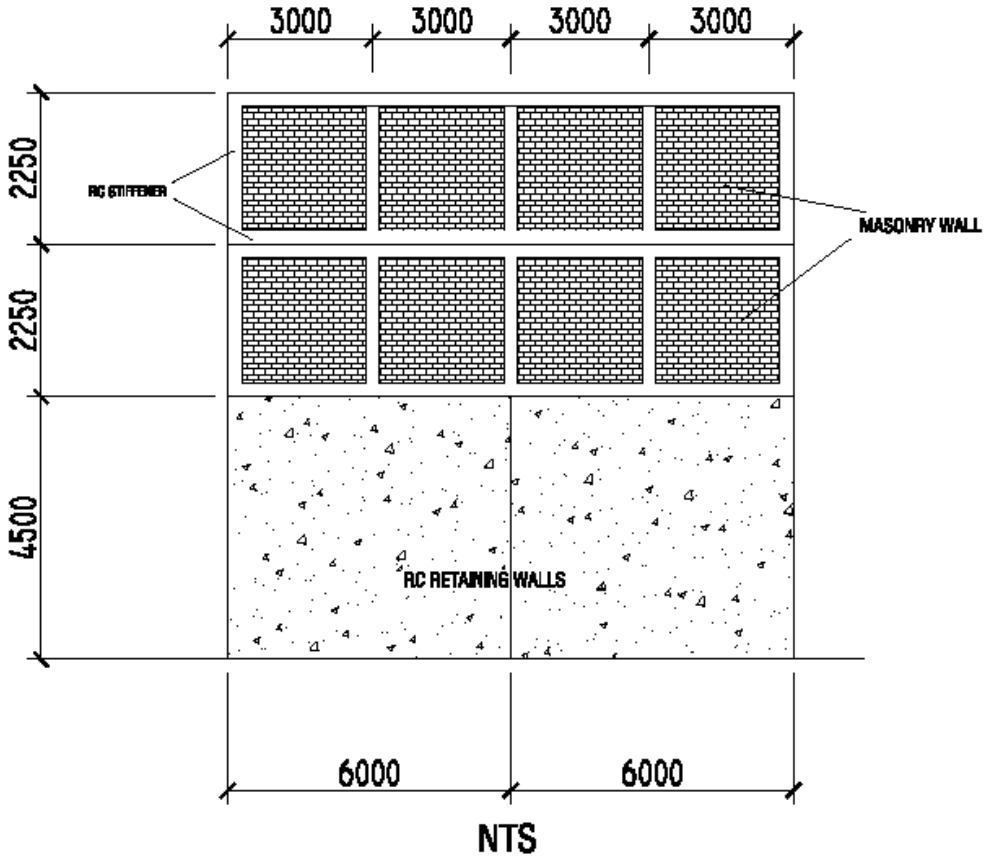


FIG.8: PROPOSED WALL IN PERMANENT STATE