1. ABSTRACT

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During Desert Storm (Gulf War), more than 158 building structures were affected due to scud missile attack in Riyadh city; eight of these structures collapsed, while there were relatively moderate to minor structural damages to other buildings and facilities. It was found that the buildings suffered as if they were exposed to ground motion.

This paper reviews the performance of the affected masonry walls and highlights qualitatively the main damaged features due to scud missile attacks in Riyadh City.

Two principal reasons for the degree of damage are: (1) The lack of provisions for lateral loading in design, and (2) Improper construction detail and practices. Most of the damages presented herein were related to non-structural masonry walls and partitions. Damage to masonry can be attributed to poor standards of design, detailing and workmanship.

2. INTRODUCTION

During Operation Desert Storm (Gulf War), the city of Riyadh was attacked by more than 20 Scud missiles. Although the explosive impact of these missiles was recorded by earthquake monitors at King Saud University with a magnitude of less than 1.5 on the Richter Scale, damage to building structures was localized and related to the distance from the explosion or impact. More than 158 buildings affected, eight of which collapsed as a result of the attacks.

Previously\(^1\) the effect of Scud missile to reinforced concrete structures was discussed. In this paper the behaviour of structures is reviewed with particular emphasis on masonry walls as cladding and/or infilling. Lessons to be learnt from this disaster for the effective design of structures have relevance not only for Saudi Arabia, but also for many other countries which are subject to earthquake risk.

Keywords: Masonry walls, Lateral load, Earthquake load, Scud Missile

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3. THE SCUD MISSILE

All of the missiles launched towards the Kingdom were conventional high explosive (about 85-100 Kg T.N.T.) weapons. Most of the heads of these missiles exploded in air, while the body itself fell on or near the buildings. Where the body or head fell directly on a building, total collapse resulted and this was recorded for two cases. On the other hand, when either section fell on ground, it caused high lateral pressure as well as earth-movement (similar to that of an earthquake), resulting in consequential damages to any nearby structure.

4. BUILDING BEHAVIOUR

Earlier3-5 observed building failures due to earthquake, with few notable exceptions, have similar damage features to the present cases. Most of the buildings which were affected by these attacks are of reinforced concrete structural frame, 2-5 stories in height, and approximately 1-15 years old. The damages are classified as:

1- Partial or total collapse: This occurred where a missile hit directly or immediately adjacent to a building.

2- Severe and moderate damages: These include buildings with various degrees of damage to the structural elements. In such cases, the Scud hit was in close proximity to the building.

3- Minor damage: This category includes fissures in structures, walls and cosmetic local damage (See Fig. 1.) occurring within 200m from the scud hit.

Fig. 1 - Old structure adjacent to new one. Note the degree of damages
Structures at a distance more than 300m from the place of impact generally performed well, and there were no significant masonry damages recorded.

5. MASONRY WALLS

Most buildings had a profusion of masonry walls which were supposed to serve merely as partitions. In some cases the presence of masonry walls was beneficial and probably prevented many collapses by providing some secondary support to the frames, even if the walls themselves did collapse to various extents (See Fig. 2).

Fig. 2 - Failure of masonry walls

A majority of the affected buildings had not been specifically designed for impact or lateral loading. The arrangement and location of masonry walls contributed to a
structural failure. These instances were due to asymmetric layout which had masonry walls on two perpendicular sides, consequently inducing torsion failure. These aspects could have been avoided by a rudimentary lateral (earthquake) analysis.

An inertia force is induced due to lateral pressure & earth movement in the direction normal to the plane of wall (face loading) as shown in Figure 3. The resulting masonry damage is consistent with that produced by a lateral load acting on a brittle material with low tensile strength. Walls and upper levels of buildings are more heavily loaded by earthquake forces and therefore are more susceptible to this form of damage. Although many walls did not collapse, they did undergo significant displacements or rotations from their original position under the action of face loading. This was due either to lack of edge support or inadequate tying. There was also evidence of differential movement between masonry walls and their supporting frames. It is therefore important that non-load bearing elements be adequately supported against face loading. It is not sufficient to rely on window frames, lintels and ceilings to provide lateral support to the top of a non-loadbearing wall.

Fig. 3- Rocking failure of masonry wall at ground floor, due to lateral pressure

Rocking failures are the result of in-place forces induced by earth motion parallel to the plane of the wall. They are more likely to occur in the lower stories where shear forces are greatest. Rocking failures by themselves usually do not result in wall collapse but can cause considerable distress in the wall (See Fig.3-4). Rocking damage was widespread in the form of hairline cracks in masonry, and cracks in internal finishes such as cement render or wall tiles (See Fig.4). In any form of framed construction, it is important that consideration be given to tying and transfer of horizontal forces between the frame and the cladding (or alternatively, to isolate the frame from the masonry). It
would be desirable to have a minimum horizontal capacity requirement for all brittle components of modern construction. If such a requirement had existed, it is very likely that the damage to construction observed during missile attack would have been significantly less.

In the light of the poor standards of workmanship, quality control, and detailing, there is a strong case for more effective implementation of correct masonry practices at all levels of the building industry, from the professional engineer and architect through to the tradesman. Even in modern, "supervised" engineered structures there were glaring examples of problems in this area. These included bad masonry procedures, no provision for movements between wall and frame, and generally poor standards of workmanship.

Fig. 4 - Rocking failure of masonry wall at ground floor, due to earth movement and lateral pressure
6. SUMMARY AND CONCLUSIONS

Damage to Masonry walls is related to the more general aspects of building construction. The following is a brief summary of some of the important points.

1- A tying system to be included which can effectively isolate the wall from its supporting frame. If such a requirement had existed, it is very likely that the damage to construction observed during missile attack would have been significantly less.

2- Non-loadbearing elements should be adequately supported against face loadings.

3- It appears that, particularly in framed structures, there is no supervision or inspection for the non-loadbearing and infill masonry walls construction. Attention must be given to such construction aspect.

It should be stressed that the problems described are not unique to such incident. It is hoped that this paper will at least alert designers and contractors to some of the potential problems which can be encountered with structures subjected to lateral and earthquake loading.

7. REFERENCES


4- Melchers, R.E. (ED), "Newcastle Earthquake Study", The Institution of Engineers, Australia, March 1990.