Solving the Puzzle

A Case Study of Building Distresses Due to Foundation Movement

By Xing Shi, Ph.D., and Mark Holland, P.E.

Every year, many building problems related to foundation movement occur that cost billions of dollars to repair. Clients frequently rely on consulting structural engineers to investigate these situations. The prelude is usually a phone call from the property owner, manager, or maintenance personnel who observed some distress on their buildings such as cracks in the wall or floor, peeling paint or floor tiles, dislocated window or door frames, etc. The structural engineer investigates the building, usually starting with visual inspection focusing on apparent areas of distress. If the problem appears to have been caused by foundation movement, the engineer will usually recommend a floor elevation survey to confirm this hypothesis and better understand the physical movement of the structure. Based on the observed areas of distress and measured floor elevation, the engineer will try to piece together a more complete picture of the physical movement of the building, and then look deeper into the problem to determine where the most critical structural damage might be. In many cases, the damage to the main structural system may not be readily visible. The engineer may also recommend some geotechnical testing to determine the characteristics of the soil. The last step is to develop a feasible and economical plan to repair the building.

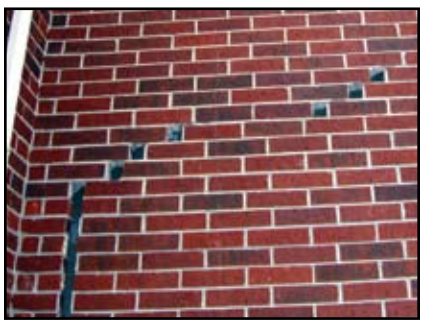

Figure 1: The major crack in the corner of the south wing brick wall.

The procedure described above is common for consulting work on building failures related to foundation movement. To some extent, it is like solving a puzzle. Starting from obvious clues (visible distresses), the structural engineer inspects the building and, assisted by necessary testing, gradually assembles a complete and truthful picture of the physical movement of the building.

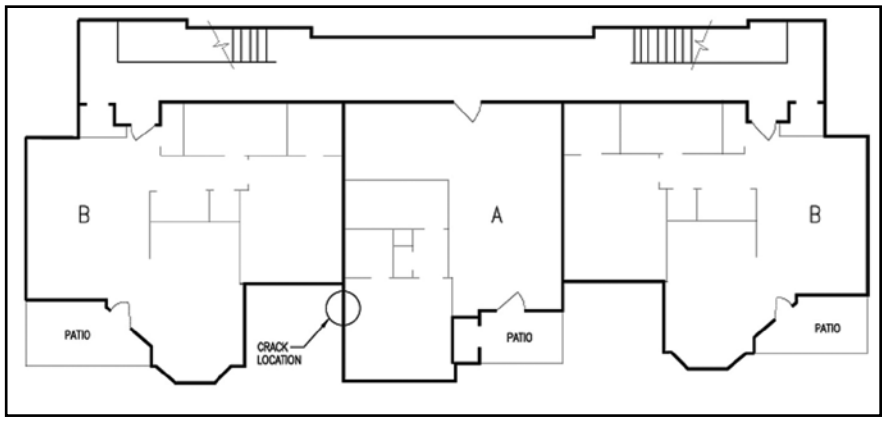

Figure 2: Floor plan of the south wing. The major crack was located in the brick wall along the left-hand side of the protruding room of module "A".

This article presents a case study of building distress related to foundation movement. The objective is to demonstrate how the structural engineer often approaches this type of work.

Problematic Building and Distress

The building of interest is located in Houston, Texas, where expansive clay is common. As usual, the project started with a phone call from the building management personnel, reporting "a big crack in our brick wall."

This building is a three-story apartment facility with post-tensioned slab-on-grade, wood stud frame and wood roof truss, and screen-type brick veneer. At a protruding portion in the south wing of the building, there was a major crack that widened as it extended from the 1st floor to the 3rd floor (*Figure 1*). On the 3rd floor, the crack was almost 2 inches wide, clearly indicating significant building movement. *Figure 2* shows a floor plan of the south wing and the location of this major crack. During the review, many other cracks, both exterior and interior, were found throughout the south wing. A person standing on the inside could feel the floor sloping down towards the end wall. Based on these preliminary findings, it was determined that these distresses were caused by foundation movement.

Finding Clues

To confirm initial speculation, a floor elevation survey was performed. The results showed that there was a floor elevation difference of approximately 2 inches between the breezeway and the end wall. This finding confirmed speculation that differential movement of the foundation caused the distress.

The next step was to develop a complete and accurate picture of the physical movement of the building, and then use it to determine the most probable location of the critical structural damage. This step was important because the main superstructure, i.e., wood stud frame and wood roof truss, was not readily visible, so relying solely on the visible distresses may have led to incorrect conclusions.

As shown in *Figure 1*, the major crack extended from the 1st floor to the 3rd floor and turned 45 degrees at the wall corner to continue until it reached the facia board of the roof. The movement was such that the side brick wall to the right of the crack rotated away from its original position. It was then quite logical to ask the question, "How did the adjacent end wall move?" Upon further inspection, using a long ladder, the top of the end brick wall was found pushed outwards by the movement of the side wall, exactly as expected. So far, the physical movement of the exterior brick walls was fully understood.

But what about the hidden structure? Was it damaged by the movement of the brick wall? To answer these questions, the wood stud frame in the attic space was investigated. The wood stud adjacent to the major crack was clearly the most suspicious location. However, those wood studs were found to be in good condition. No significant movement, bending, or twisting was evident. Is it possible that only the brick wall

suffered significant damage, and that the main structure, i.e. wood stud frame and wood roof truss, remained intact?

Figure 3: Gap between the ceiling and the siding wall on the 3rd floor.

Solving the Puzzle

The bottom of the major crack can be considered as a "hinge" for the side brick wall. The wall rotated around this hinge from its original position. Since the floor elevation survey suggested that the whole south wing moved, it was reasonable to presume that the main structure also had developed a similar hinge. But where was it?

A discovery in the 3rd floor breezeway led to the last piece of the puzzle. As shown in *Figure 3*, a gap of about 1 to 2 inches wide between the ceiling and the siding wall was discovered. By cutting out a piece of sheet rock from the ceiling, the gap and the bearing of the wood roof truss could be observed. *Figure 4* shows a picture of the condition of the bearing of the roof truss. It is clear that the roof truss also "rotated" away from its original position. As a result, nails had partially pulled out, and there was a gap of approximately 2 inches between the end of the truss and the wood stud. This was exactly the "hinge" location of the main structure.

With all of the relevant information gathered, a complete and accurate picture of the physical movement of the whole building, including the exterior brick wall and the hidden wood stud frame and roof truss was available. The puzzle was solved!

To further confirm and better understand the cause(s) of the foundation movement, the structural engineers recommended the following additional investigations:

- Soil boring test to determine the characteristics of the soil underneath the south wing.
- Plumbing leakage testing.
- Testing of the prestress level of post-tensioning tendons.
- Review of the post-tensioned slab-on-grade design. Inadequate design of the post-tensioned slab-on-grade might have contributed to the differential movement of the foundation.

A conceptual design strategy was also recommended. It involved installing precast segmented concrete piers around the perimeter of the post-tensioned slab-on-grade, using these piers to jack up the building back to its original position. The void created underneath the slab-on-grade would be filled with expansive foam material.

Figure 4: Bearing of the wood roof truss. Note the pulled-out nails.

Lesson Learned

Building distresses related to differential foundation movement are fairly common. In many cases, the client sees some visible damage and contacts a structural engineer. The engineer usually starts the project by reviewing the visible distress of the building to determine whether it might indicate differential foundation movement. A floor elevation survey is a good tool to help reach the correct conclusions. Although the movement of the exterior and visible parts of the building – in this project, the brick wall – is relatively easy to determine, it requires careful consideration and sometimes destructive testing to discover the movement and possible damage of the hidden structure. Only based on a complete and accurate understanding of the movement and damages, including both the visible and hidden portions of the building, can the structural engineer correctly identify the problem and recommend feasible and economical solutions to the client.▪

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