DISCUSSION

J. G. Stockbridge[1] *(written discussion)*—I personally had the opportunity to investigate the cause of the masonry distress in three of the six buildings discussed in this paper, Case Histories I, III, and V. In two cases, I worked for the building owner and on the third I worked for the developer. In all three cases, Gensert and Bretnall worked for the company that provided the mortar which was used in the buildings.

The masonry distress in all three buildings was caused by corrosion-induced cracking rather than the causes cited in the Gensert/Bretnall paper. The mortar used was breaking down and releasing tremendous amounts of chloride. Laboratory tests on samples removed from the buildings discovered chloride levels 10 to 40 times (not percent) higher than the amount known to cause corrosion of embedded steel. Galvanized coatings were being completely eaten away, the base metal of embedded steel elements were severely corroding, and the buildup of the rust product on the steel was causing cracking and spalling of the masonry.

Case History I: a bank—The paper fails to mention that the reason the horizontal joints were unable to accommodate volume movements was because they were filled with rust product from the severely corroding horizontal leg of shelf angles. Also, when inspection openings were cut into the piers, it could be seen that severe rust buildup on the face of the vertical legs of the angles were prying the piers apart and also causing cracking. The corrosion buildup on the leading edges of the horizontal legs of the shelf angles at the alternate levels without movement joints was shoving whole sections of mortar laterally out of the joints.

Case History III: a hotel—Vertical cracking developed at the vertical reinforcing bars because they were severely corroding. When inspection openings were cut into the panels, it could clearly be seen that the rust buildup on bars was causing the cracking. The cracks were radiating out from the corroding steel. The cracks were not externally induced.

In addition to the cracking at the vertical bars, corrosion-induced cracking and spalling was occurring at corroding pencil rods at free edges of panels, vertical cracking was occurring at corroding lifting lugs, and crescent-shaped spalling was occurring at corroding connections.

Cracks took longer to develop at the center bar than at the outer bars because rust-induced outward bowing of the panel was restrained at the center bar.

Casė History V: a mall—The cracking at the roof connections of the high parapets was not caused by restraint of panel bowing. It was caused by pressure from rust buildup on the severely corroding anchors at the roof line.

Corrosion-induced cracking was also occurring at anchors in spandrel panels and at lifting lugs. There was even cracking occurring at anchors which had never been used and were attached to nothing. The reason the cracking was more severe on the high parapet panels than on the low parapet panels was because the severely corroding connections in the high parapet panels were closely spaced at 16 in. on center while in the low parapet panels they were spread out at 40 in. on center.

W. G. Hime[2] *(written discussion)*—It is distressing that Messrs. Gensert and Bretnall present an analysis of curtain walls of six buildings without noting that: the masonry of five of the six was made with mortar additive of the company that employed them; that severe corrosion occurred to metals in contact with or embedded in the mortar; that engineers, chemists, and metallurgists have attributed most of the distress experienced by those buildings to corrosion

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[2]Erlin, Hime Associates Division, Northbrook, IL 60062.

caused by the production of chloride ion through degradation of the saran latex component of this mortar; and that they (Gensert and Bretnall) were experts employed by this company to investigate those buildings. (The author of this discussion was employed by plaintiffs in lawsuits filed against this company in relationship to the distress.)

Gensert and Bretnall's first example is particularly of note because it went to trial, and a jury held against the company that employed them for over 25 million dollars including punitive damages. According to public records, this company appealed the verdict and later settled for about 19 million dollars. The records also indicate that the other buildings the authors describe, but do not name, and which contained the same mortar, were the subject of suits that were settled by this company for amounts ranging from a few million dollars to over ten million dollars.

Considering that five of their examples contained the masonry in question, none of these authors addressed the significance of such statistics.

C. H. Raths[3] *(written discussion)*—Messrs. Gensert and Bretnall in the verbal presentation of their paper elected to discuss masonry building problems using a bank and a hotel, both located in Cleveland, a manor in the Philadelphia area, and an apartment building, also near Philadelphia, as examples. The bank project was constructed using in-situ brick masonry and the mortar in question. Prefabricated brick panels were employed on the other three projects in which both the hotel and the manor had panels fabricated with this mortar. The apartment house used a proprietary grout in the panel instead of mortar.

The presentation of the paper regarding the three panel buildings indicates that a main cause of the observed cracking and distress is differential structural responses between the panels and the building frame. These structural responses, according to Gensert and Bretnall, result from *rigid* connections attaching the panels to the structural frame. Because the connections are rigid and restrain movements, they induce cracking stresses into the panels when the panels are acted upon by temperature, creep behavior of concrete building frames, moisture expansion of brick, building lateral shear forces, weak planes within panels, etc. Also, it is offered that panel cracking directly over reinforcement results from a stress riser effect of the rebar within the brick cores.

No mention is made by the authors of the extremely excessive amounts of the Cl^- within the mortar in question nor the extensive corrosion suffered by the reinforcement and other embedded metal (with and without protective coatings).

This writer, as well as other qualified engineers, has been involved in investigating, analyzing, and testing these four projects. Relative to the panelized projects, visual evidence of distress and deformation or failure about connections was not typically present. And, considering the magnitude of forces which would be attracted to rigid connections, shearing and bearing stresses should occur which would cause complete failure of the connection itself and the adjacent brick. Yet, neither distress nor structural failure of the connections has occurred other than that resulting from corrosion caused by Cl^-.

The conclusions about panel cracking and distress generated by rigid connections rest upon analyses which do not recognize load-deformation characteristics of the connections but instead consider connections absolutely rigid. Structural testing by the writer has provided data on the load-deformation spring characteristics of these brick panel connections. Analyses using connection springs, which provide significantly reduced restraint to panel movements, has indicated that the magnitude of restraint forces induced into panels are small and will not produce cracking distress. The analyses coincide with the observed behavior.

Gensert and Bretnall suggest that the cracking in the panels of the apartment house resulted from a stress riser effect in the brick caused by vertical panel reinforcement. In-depth petrographic and related testing determined that the in-plane cracking of the panel was a direct

[3]Raths, Raths & Johnson, Inc., Willowbrook, IL 60521.

consequence of proprietary grout freeze/thaw deteriorations. Structural behavior of the panel was not a factor in the cracking. Reinforcements within the cracked panels were not corroded, and no chlorides were present in the grout.

Restrained differential movements between in-situ or panelized brick masonry and the building frame can and do lead to a certain amount of distress as correctly characterized by Gensert and Bretnall. But, once cracking occurs about connections, the restraint is basically relieved and further cracking does not develop. And, for mortars and grouts not containing Cl^-, corrosion of reinforcements at these relief crack locations does not occur. The cracking described in the paper cannot happen without some other factor being involved. As discussed by this writer, Cl^--caused reinforcement corrosion and freeze/thaw deterioration of grout are the other factors leading to the paper's reported cracking and distress. Thus, the conclusions reached and presented by Gensert and Bretnall relative to problem causes are in error and the result of incorrect analyses and/or improper site investigations.

G. P. Chacos[4] *(written discussion)*—As the structural-engineer-of-record of the building described in Case History III, I am obliged to submit additional information for those interested in understanding the facts of this case. In addition to providing the structural design of the building, I reviewed the fabricator's design and shop drawings of the brick panels and have closely studied the distress in these panels.

I take exception to many of the assumptions and conclusions presented by the authors in their discussion of Case History III. Their investigation was one of many done on behalf ofthe company that employed them to prepare for lawsuits centering around claimed corrosive tendencies of a mortar additive supplied by this company. It is surprising, if an unbiased investigation is the objective, that their discussions do not include some reference to possible detrimental effects of chemical interaction between the components of the panels.

There have been no problems with the structural performance of the brick panels. Load tests of full-sized panels verified the composite design of the stiffened, reinforced panels prior to their installation. Properly designed soft joints and flexible connections were used, and no instances of fully compressed horizontal joints or fully compressed vertical joints have been reported. The forces indicated on Figs. 29 and 30 cannot occur with the real connections.

On Fig. 31 the authors show the vertical cracks which occur at the locations of the three vertical rebar in each of the most common panels on the north and south faces of the building. The top floor panels, however, have four vertical rebar and four vertical cracks, totally inconsistent with the "accordian" pattern of failure described. It is my observation that the cracks are caused by corrosion of the rebar, and I dispute the authors' contention that corrosion of the rebar came after the cracks occurred.

I agree with the authors that it is necessary to examine all possible sources of distress when analyzing a problem, but the discussion of Case III does not present all of the facts and forms conclusions based on an inaccurate model.

Author's Closure

The number of discussion papers received indicates that there is keen interest in the subject of masonry curtain wall distress and that this topic should be a matter for lively debate. It should be pointed out that the discussers, except for one, are an organized group of professionals working collectively for the plaintiffs which they cultivated throughout the country.

In response, additional information is offered:

[4]Gregory P. Chacos, Inc., Cleveland, OH 44115.

Case History I

Horizontal movement joints were provided approximately every 15 m (50 ft) and were filled with 6.35-mm (1/4-in.) compressible material. Deflection of the supporting cantilever bracket, moisture expansion of the masonry, and a temperature rise of 28°C (50°F) will close the joint.

The vertical legs of the shelf angles do not have enough stiffness to pry the piers apart. For the prying force to be a factor, the piers on the front and side faces would have been displaced outwards. In fact, piers were cracked on the front face only.

It is interesting to note that cracking occurred at high stress concentrations even though rusting was not always present. Text books on masonry expansion and B.I.A. Tech Notes were totally disregarded.

The recent history of this building is particularly significant. All masonry near steel framing was replaced in 1979 using mortar containing no additives. All embedded metal was replaced with new metal protected with multiple coats of epoxy paint. The reconstruction of the facade followed the original design. Today, eight years later, the facade has become distressed in the same locations and in the same pattern as the original distress. The origin of the distress is clearly due to the structural action between the masonry and the supporting frame. The authors are not alone in this opinion. Charles Raths, who examined the building at about the same time as the authors, wrote in his summary report:

> The visual examinations made by RRJ resulted in identification of certain conditions which were of a repetitive nature. Among repetitive conditions noted for the . . . office building were the following:
>
> B2. Tapered vertical and horizontal brick cracks in the intermediate piers resulting from structural frame deformations.

Case History III

The owners of this building documented, very thoroughly and very carefully, the progression of the distress in three separate (but not consecutive) years. A detailed study of this documentation shows that there is a very clear pattern, consistent from panel to panel, to the progression of the distress. The total length of cracking at embedded metal is substantially <u>less</u> than the total length of cracking away from embedded metal. If corrosion of embedded metals caused the cracking, there would be no clear consistent pattern, and certainly no cracking where there was no metal.

The authors are aware of only one load test of a stiffened panel. This test was performed by laying a panel flat and having a group of men stand on it. The test was not conducted in a controlled, scientific manner.

The steel connections between the panels and the structure are rigid and show signs of distress due to structural interaction between the panel and the structure. There were many documented instances of fully compressed horizontal joints. These joints closed because of the expansion of the brick and the creep shortening of the concrete frame.

Case History V

It is significant that the tall parapet panels of this building cracked on only two sides of the building—those with the greatest thermal exposure. Yet support details and construction are identical on all four sides. Thermal differentials of as much as 22°C (40°F) were recorded across the thickness of a cracked panel on a sunny but relatively mild day, with the outside face being the warmest. Bowing of the panels did occur.

Cracking at the lifting bolts or lugs is due to extremely high prying forces generated during handling. These lugs were not only used to lift the panels but also to rotate them 90° from their as-built orientation to their in-place orientation. Entry of water and formation of ice during the winter propagated initial cracking.

Summary

The distress seen in all these masonry curtain walls has a common origin: structural interaction between the curtain wall and the supporting frame.

Of conclusive evidence: the patterns of distress in masonry using the mortar additive also occur in masonry which does not use the additive. Further, nonmasonry curtain wall systems investigated by the authors exhibited similar distress for the same reasons.

The lesson learned from these case histories is that curtain walls must be designed to allow for the movements that do and will occur between the curtain wall system and the supporting frame.

It is most surprising and distressing to the authors that many in the profession investigate only to the seemingly obvious and compelling conclusion for their clients, yet refrain from further research to seek out the underlying and motivating factor of a structural phenomenon, in this instance that a certain masonry additive causes masonry distress regardless of design application or construction technique. Yes! Some chemical additives can accelerate corrosion. But what is required to initiate corrosion? A basic fact of chemistry is that water and oxygen promote corrosion. If masonry cracks from structural distress, it is obvious that water enters the masonry and corrodes the steel. Conversely, if the masonry does not admit water to the steel, there is no corrosion, as has been documented.

It is our contention, corroborated by several decades of private practice experience and coupled with extensive university teaching and research, that the interaction of structural systems and the systems they support are so sensitive as to require isolation of the supported system.

Perhaps there is a greater lesson to be learned here. Let us benefit from the documented past. Let us understand the problems. And in so doing, reduce our forensic efforts and direct our energies toward creating structures that will stand the test of time.