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November 15, 2019 VIA E-MAIL

Mr. Brian Dusak
Principal/Project Manager
Engineering Resource Associates, Inc.
3S701 West Avenue, Suite 150
Warrenville, Illinois 60555

RE: ERA - Moser Tower
Special Structural Analysis of Moser Tower
RRJ 19072

Dear Mr. Dusak:

This report is considered a summary of Raths, Raths & Johnson, Inc. (RRJ) evaluation of the Moser Tower following our proposal dated April 19, 2019. RRJ proposed two tasks to clarify and define the likelihood of additional deterioration of the concrete of the tower from structural sources yet undefined by previous investigations. One was a review and organization of the observed distress, cracking, and spalling, and the other was a structural analysis of the tower to determine the potential of other causes for the major spalling at Level 116.7. Therefore, this report is intended to build on the work of others summarized by the Engineering Resource Associates, Inc. (ERA) Moser Tower Structural Assessment dated April 2017 (ERA 2017 Report). The ERA 2017 Report states that it is a comprehensive assessment of the current condition of the Moser Tower structural elements and provides summaries of the work of others involved in the project since early 2005. It was updated in 2019 with the addition of Addendum NO.1 (DRAFT) by ERA in March 2019 (ERA 2019 Addendum).

The RRJ investigation followed a meeting on April 2, 2019, at which concerns were expressed that as of that date, there was not a clear understanding of the cause of the re-failure of structural patches located on the south side of Level 116.7. These repairs had failed previously in 2005 with the spalling and cracking of the precast tower column/panel elements above and below grout pockets provided to protect the post-tensioning anchors just below the joint at Level 116.7. The logic of this needed information was to avoid subsequent patching re-failures in the future.

Several conditions or actions could have been present that may have contributed to the re-failure of the patching working in combination with grout expansion due to the presence of gypsum in the stressing pocket grout. Some of these conditions include tower movement due to wind loading, local overstress due to the combined effects of gravity, wind and post-tensioning stresses, or a large stress build-up or a concentration of bearing stresses due to the grout setting bed at the Level 116.7 joint. RRJ proposed a plan to perform a structural analysis of the tower to evaluate the stresses created by the various possibilities so that they could either be addressed or dismissed. In order to fully explore the potential contribution of the post-tensioning to the distress, RRJ contacted Dave Martin of DWIDAG-Systems International (DSI), the manufacturer and installer of the post-tensioning for input regarding his product because the DSI product is a very specialized form of post-tensioning, and includes specialized hardware and procedures to install and stress the tendons/bars. Mr. Martin and his staff are specialists in the design, repair, and maintenance of DWIDAG Post-Tensioning system components.

TASK 1: REVIEW OF AVAILABLE INFORMATION REGARDING THE MOSER TOWER DISTRESS

The initial step in the RRJ investigation was to gather and review the observations of others relating to the cracking and spalling of the precast tower elements. The intention was to gain an overview of the tower behavior to look for patterns of cracking or spalling that would suggest types of causation that may not have been previously considered.

The main tower components were erected from 2000 to 2001. At this point, lack of funding caused a pause in construction, and the precast fins and other internal steel elements were not erected until later. The principal precast piers were erected by 2000. Between 2000 and 2004, several significant, large cracks were observed which developed into major spalls at Level 116.7. Some of these caused concrete pieces to fall from the tower.

ESI was the first to be asked to examine the precast concrete, in particular, the larger areas of cracking and spalling at Level 116.7. The ESI report entitled *Naperville Carillon Structural Cracks Consulting* was issued March 1, 2006. ESI provided several photographs in their report, generally focusing on the southeast and southwest spalling precast elements. Unfortunately, little information regarding the location of the distress or other particulars were provided with the photographs. The descriptions were general and contained little specific engineering information helpful to establish if the distress was observed at all corners of the four precast piers at Level 116.7 and other locations. Spalled concrete pieces were submitted to CTL Group for petrographic examination, and gypsum contamination was reported at the post-tensioning grout pockets that caused the grout to expand and spall off the precast concrete. The ESI report conclusion suggests other cracking without spalling was observed at grout pockets lower in the tower, but does not identify where specifically, and the report is silent regarding similar cracking or spalling at other precast grout pockets beyond Level 116.7.

The ERA 2017 Report indicates that recommendations were made to remove all of the contaminated grout and any unsound concrete. The Phase II repairs were completed, and it is possible that not all the contaminated grout was removed, especially grout in uncracked or un-spalled grout pockets. This work was completed in 2007.

By 2015 additional cracking and delamination or limited spalling had reoccurred, necessitating the second major inspection and evaluation conducted this time by ERA, who examined the interior of the tower and Collins Engineering (Collins), who conducted an examination of the exterior. These inspections were accompanied by hammer soundings to locate loose concrete. Collins provided detailed and coordinated information, including annotated drawings, referenced photographs, and notes describing what they had found. The only cracking and loose patches or loose concrete documented by Collins were at Level 116.7 on the south elevation (Sheet A-1). The north faces contain no observed spalling or significant documented cracking. The only other significant spalls described are on three fins at other levels.

Recommendations for subsequent, more detailed investigations were made in 2017 and reported by ERA in their 2017 Report. The report contained recommendations for structural analysis and further investigations by other disciplines to better refine the needs for repair and the condition of the tower. The principal focus was to develop repair and maintenance costs so that the City of Naperville could fairly evaluate the cost to move forward with repairs or demolition.

Additional investigations were undertaken, as described in the ERA 2019 Addendum produced in March 2019. Keeping to RRJ's principal scope to evaluate the main structural deterioration focusing on the spalling and re-spalling at Level 116.7, components of the ERA 2019 Addendum pertinent to our evaluation would be the Brush Architect Report, especially the detailed observations of the spalling at Level 116.7, detailed recommendations regarding the need for a structural assessment, and the Condition Assessment drawings summarizing the locations of the various types of concrete distress.

Therefore, the result of the RRJ review of available information regarding the Moser Tower concrete distress was that contaminated grout was used in the grout pockets of the south side of the tower at Level 116.7 and likely caused expansion, which burst the precast outer shell of the grout pocket at the post-tensioning anchors above and below the precast joint at Level 116.7. No mention of similar distress was found at grout pockets on the north side at Level 116.7, where it would be expected if the same grout mix containing gypsum were used. Although it is possible that different grout mixes were used in grout pockets, the results are inconclusive regarding the distribution of cracking and spalling because the location of other spalling or significant cracking was not described. This could be because none was found, or it could have been present and not recorded. ESI contended that other grout pocket spalls were observed, but they were not identified. Collins did not report any other grout pocket spalls, and the Brush Architect Report does not identify any other grout pocket spalls. (Fin spalls are described at three locations, but these are not the same as the grout pocket spalling and distress.)

In order to referee this question for Level 116.7, where one would expect to see similar grout pocket spalling on the north elevation of the tower precast, RRJ employed our drone and filmed these areas. The drone does not have the resolution to reliably detect small hairline cracking that could go unnoticed. No significant cracking or spalling was observed, further suggesting a different grout was used on the north side. The presence of gypsum contaminated grout theoretically could be expected to cause spalling at some point in the future, necessitating repairs. However, it should also be noted that if cracking or spalling has not occurred at other post-tensioning grout pockets by now, some 19 years later, it is not likely to occur, and the pocket grout is likely stable. But to eliminate the likelihood of further re-failures, RRJ recommends that grout samples should be extracted and tested for gypsum to resolve the issue.

Another outcome of the review of the Moser Tower distress was to reveal that no other types of visually identified distress were reported, which could likely have been caused by a general structural behavior, such as overload due to external or internal loading. This suggests that the principal focus of future deterioration would be the conditions surrounding the contaminated grout pockets at Level 116.7. To verify this, a detailed structural analysis of the tower was recommended to evaluate the stresses caused by environmental factors considered in the design of the tower.

TASK 2: DETAILED STRUCTURAL ANALYSIS OF THE TOWER

The second task of RRJ's scope of work was to examine the concrete stresses and structural behavior of the tower elements due to environmental forces of wind, post-tensioning, and gravity loads to determine if stresses would be large enough to cause future distress, creating the need for repairs if they were not considered in the repair design. To do this, RRJ employed the SAP 2000 finite element computer software to model the tower main structural system, which consists of modeling structural precast concrete panels with shell elements and the steel lateral resisting frame members with frame elements. Post-tensioning was modeled as forces placed where the post-tensioning was called for or shown on the precast concrete shop drawings. The model utilized a fine grid of elements to allow coordination of the post-tensioning and connections to the structural lateral resisting frame and the sloping geometry of the precast wall panels. Two views of the model are provided as Figures 1 and 2. The member properties were based on the project information and utilized 5,000 psi for the precast concrete 28-day design strength. The code prescribed wind loading (1996 BOCA with 1993 ASCE 7-93) as described in the original structural General Notes as 75 mph fastest mile wind speed was used. Hand calculations were employed to determine the concrete bearing stresses beneath the post-tensioning bearing blocks.

The model results were discussed with DSI staff and revealed no surprises. Low stresses and small top deflection were all well within normal allowable stresses and displacements suggested by industry standards and the building code (Figures 3, 4, and 5). The computed results were as follows:

Dead Load stresses	47 psi
Wind Load stresses (Compression)	110 psi
Post-Tensioning P/A Compression	150 psi
Load combination 1.2 DL + PT + 1.3 WL	349 psi
Service Load Combination DL + PT + WL	307 psi

Top deflection under code prescribed load combination of DL + 0.7WL is 0.43 inch.

Allowable deflection recommendations from ASCE 7-93 is L/600 or 3 inches for the top of the tower.

The significance of these findings is that none of the stress levels are large enough to influence the cracking or spalling observed individually or in combination, indicating that the deterioration at the stressing grout pockets is due to the gypsum contaminated grout and was not affected by any of the stresses due to wind, dead loadings, or post-tensioning forces. Figure 6 provides an isometric view of the grout pocket and post-tensioning, showing the general arrangement and the spall plane. So, once we are certain that the grout does not contain any expansive agents, the repair, if properly designed for anchorage and movement at the joint at Level 116.7, should be expected to provide adequate longevity.

RECOMMENDATIONS REGARDING GROUT POCKET SPALL REPAIRS

Based on the results of the structural analysis and the examination of the collected data on cracking and spalling gathered to date, RRJ recommended additional examination of all eight grout pockets at the 116.7 Level. This inspection should carefully examine the precast concrete for evidence of cracking, indicating a preeminent spall. The rest of the tower should be checked for evidence of cracking at the remaining grout pockets to insure that none have been missed if cracking is present. The area of concrete exposed on the south panels at Level 116.7 at the spall should be carefully examined and probed by DSI to determine that the bearing region and tendon/bars are in good condition, sound, and not corroded. Samples of the grout remaining should be removed and tested to determine if gypsum has been completely removed. Other grout pockets at Level 116.7 should be cored to extract a grout core to be submitted for examination and evaluated for gypsum.

RRJ initially recommended that this work be done prior to the development of repair design and bidding to avoid being surprised while under construction, which could open the contract to change orders and additional costs. Out of scope time was spent by DSI and RRJ to develop a proposal to access the tower to do this work. Unfortunately, access was found to be too expensive to make the examination feasible before repairs, and it was decided in consultation with ERA to delay the additional work until the beginning of the repair and take special precautions in bidding the work to minimize the likelihood of related extra contractor costs should gypsum be discovered. One way to do this would be to bid the project to include the repair of the known spalls on the south elevation requiring removal of the gypsum contaminated grout and require the contractors to provide an add alternate to include similar grout removal repairs to the north grout pockets too should it become necessary based on inspections and testing. Also, make an allowance for inspectors' access using the contractors provided job access for inspection and sampling and allow a brief period to have the grout tested for gypsum. If gypsum is not found, the contract would continue as bid if gypsum were found, then the add alternate would be followed using the bid values for the alternate.

It is recommended that DSI be employed by the contractor to do the careful grout examination and removal as well as the inspection of the remaining grout pockets given their superior skills and experience since working around the post-tensioning anchors is potentially hazardous if done by persons unfamiliar with high bursting stresses found below stressing anchors.

RRJ also recommends that the tower distress should be rechecked just before repairs to bring the repair quantities current and mark or highlight the various types of repairs to be done. The Brush Architect Condition Assessment drawings would be a good starting point for the outline of the update of work required and drawings at a larger scale showing the length of cracking and size of spalls to allow quantities to be evaluated for bidding the repair work. This task should be accomplished at the start of the repairs using the contractor's access system for the repairs, and the contractor should be asked to confirm his quantities and costs to repair the distress items.

GENERAL REPAIR COSTS LEVELS

RRJ has been asked to provide general thoughts regarding the cost of the work at Level 116.7 for the purpose of quantifying the overall project repair cost versus demolition. Although RRJ is not a cost estimator, DSI and RRJ looked at the initial cost estimates prepared previously and felt that they were reasonable based on what we know now. The additional costs for the repair of the grout pockets on the north, should they become necessary, involve the same number of pockets as the south, but the precast is not now spalled or cracked and would be about the same cost as the south repair costs that have been estimated. Additional cost to evaluate the grout and perform other inspections as recommended above should not increase the cost of the project greatly and could reduce the overall cost as uncertainties would be eliminated. It is suggested that the repairs to the north would be about $50,000, if necessary, while the additional inspections would be expected to be about $25,000. Testing of the cores would be about $1,500 each or about $10,000.

Should you require further elaboration or explanation, please contact me. It has been a pleasure working with you on this interesting project.

Sincerely,

RATHS, RATHS & JOHNSON, INC.

Otto C. Guedelhoefer III, S.E., SECB, F.ASCE
Principal

OCG/lmd

Encl.: Figures 1 through 3

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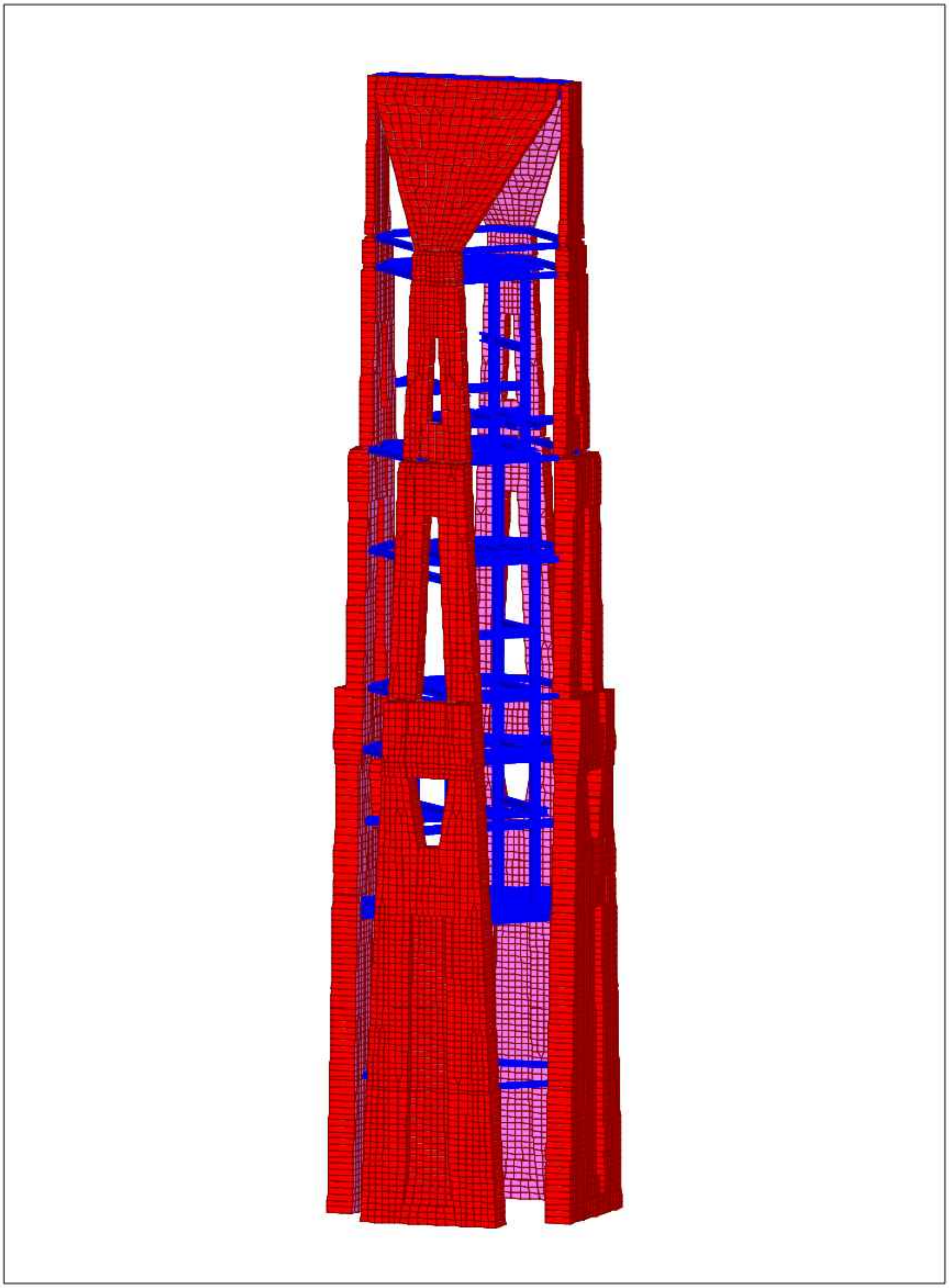
Tower07.sdb 8/9/2019



SAP2000 21.0.2 3-D View Kip, in, F

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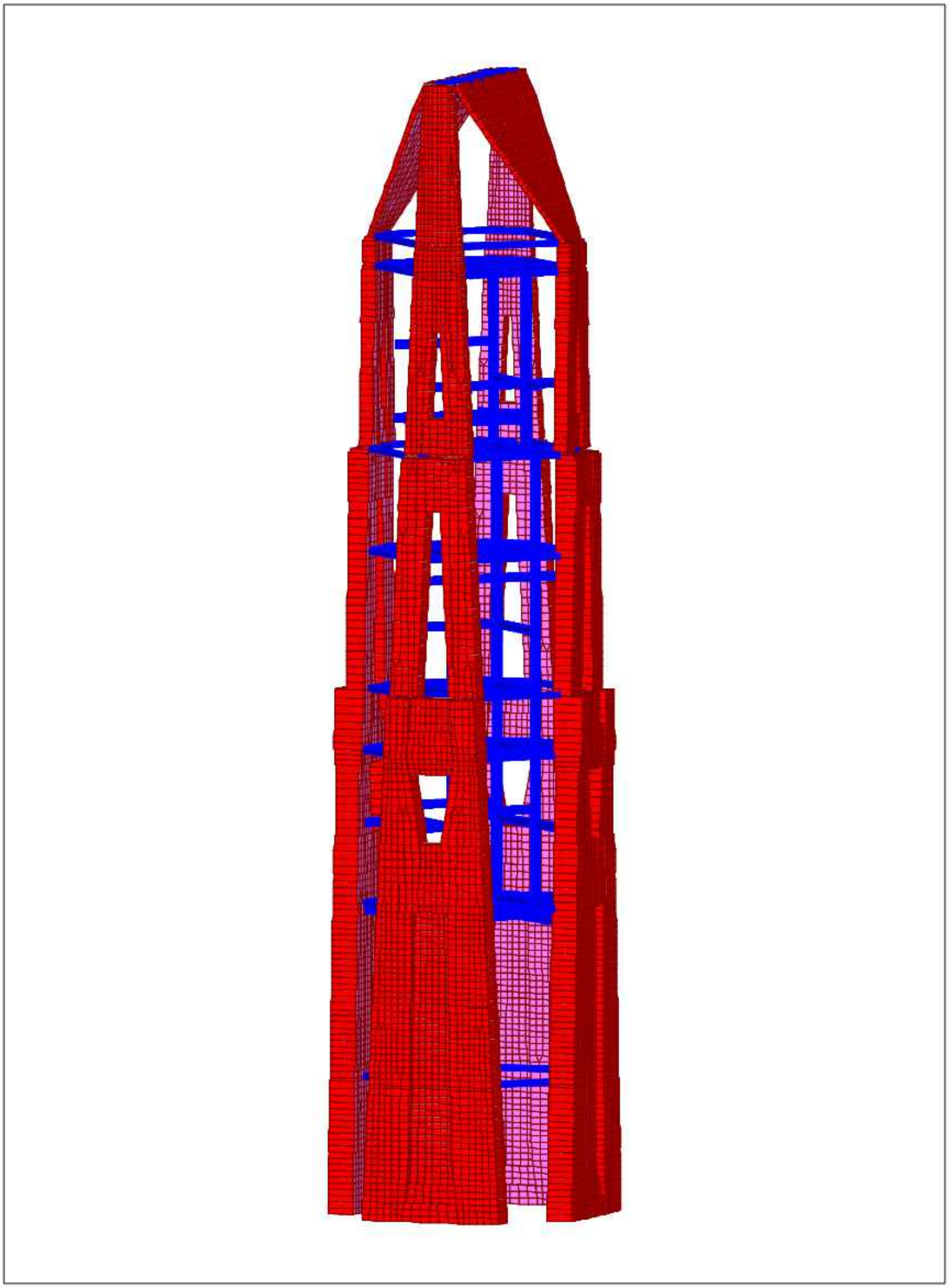
SAP 2000 PLOT
ERA - MOSER TOWER
NAPERVILLE ILLINOIS

DATE:	11-15-19
SCALE:	N.T.S.
JOB #:	19072
DRAWN BY:	BAG
PRINCIPAL:	OCG
CHECKED BY:	CWG

FIGURE 1

Tower07.sdb 8/9/2019



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SAP 2000 PLOT
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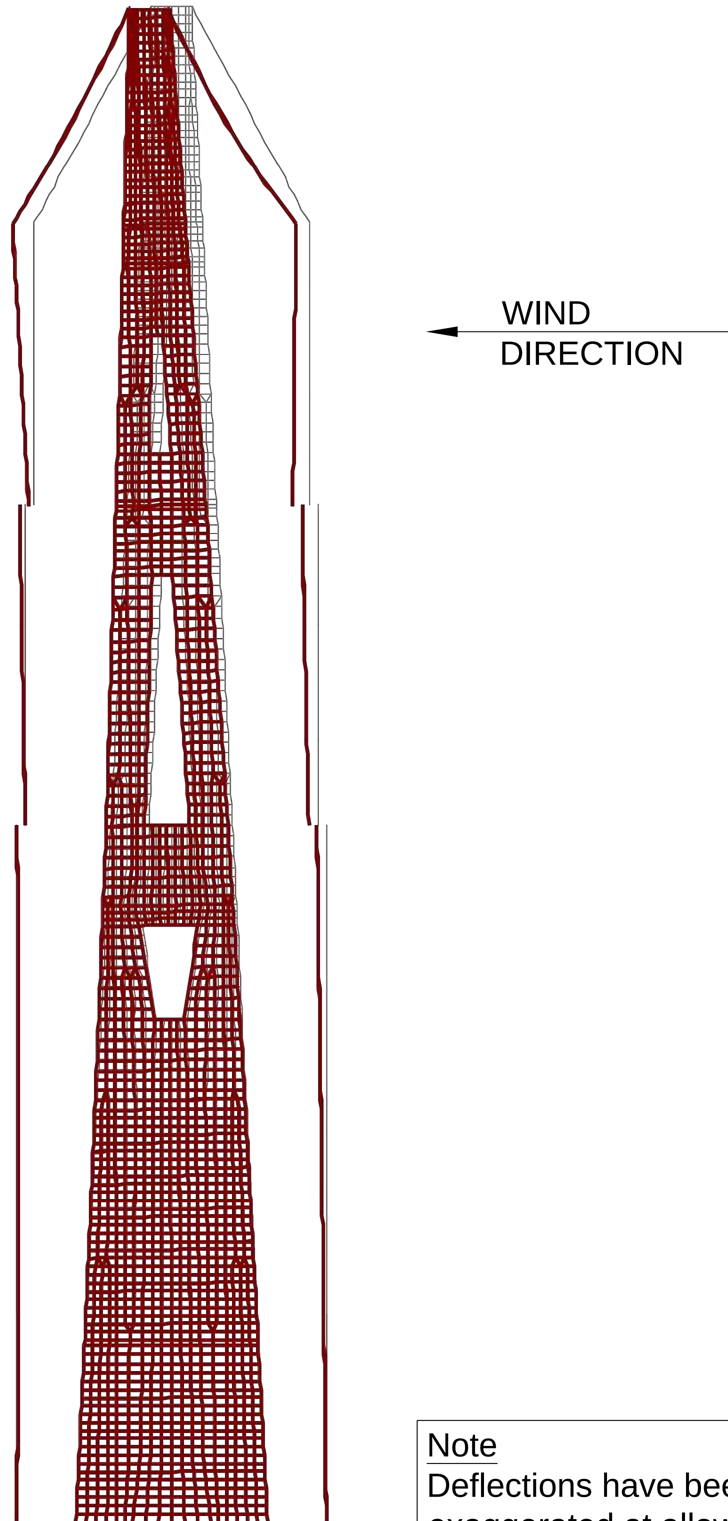
2
FIGURE

Tower07.sdb 8/9/2019



Note
Deflections have been exaggerated at allow them to be seen.

SAP2000 21.0.2 Deformed Shape (D+PT+W-X) Kip, in, F

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DEFLECTED SHAPE PLOT
ERA - MOSER TOWER
NAPERVILLE ILLINOIS

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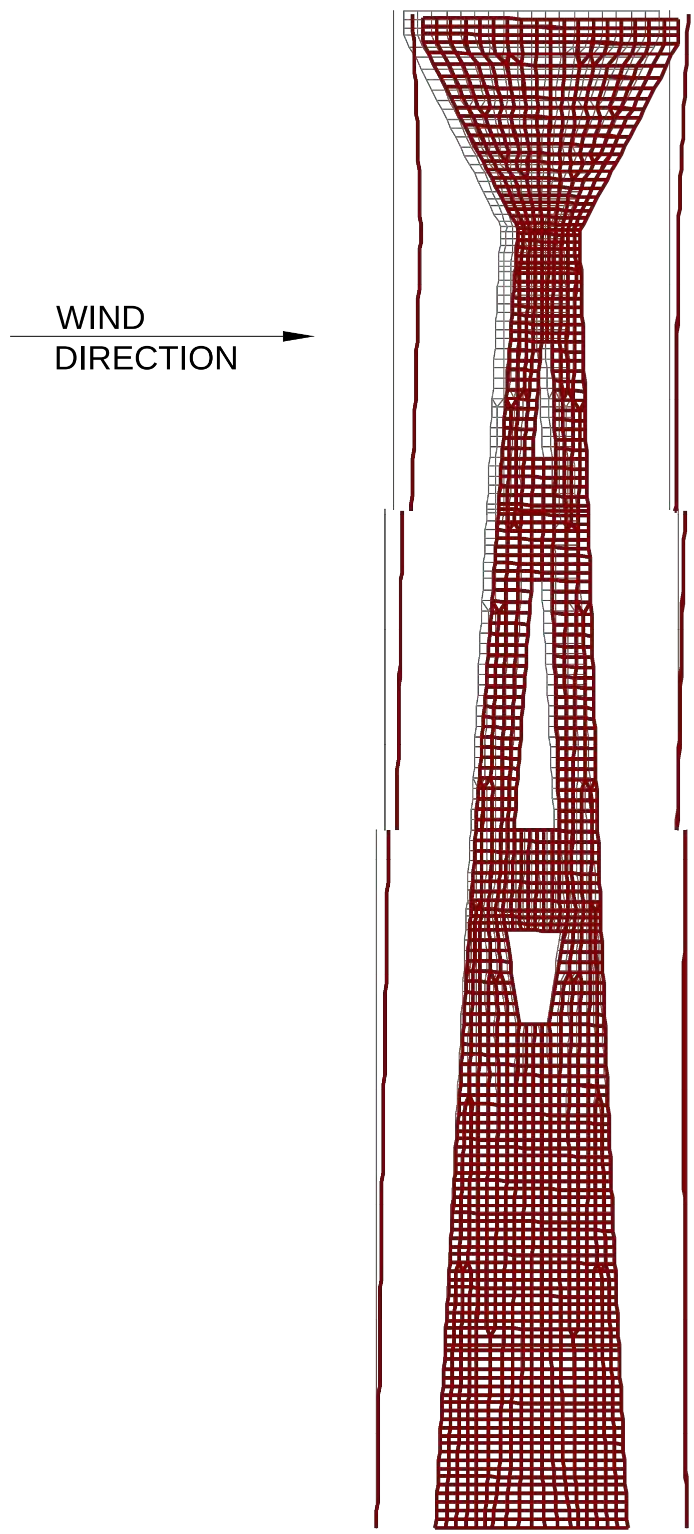
3
FIGURE

Tower07.sdb 8/9/2019



Note
Deflections have been exaggerated at allow them to be seen.

SAP2000 21.0.2 | Deformed Shape (D+PT+W-Y) | Kip, in, F

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DEFLECTED SHAPE PLOT
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NAPERVILLE ILLINOIS

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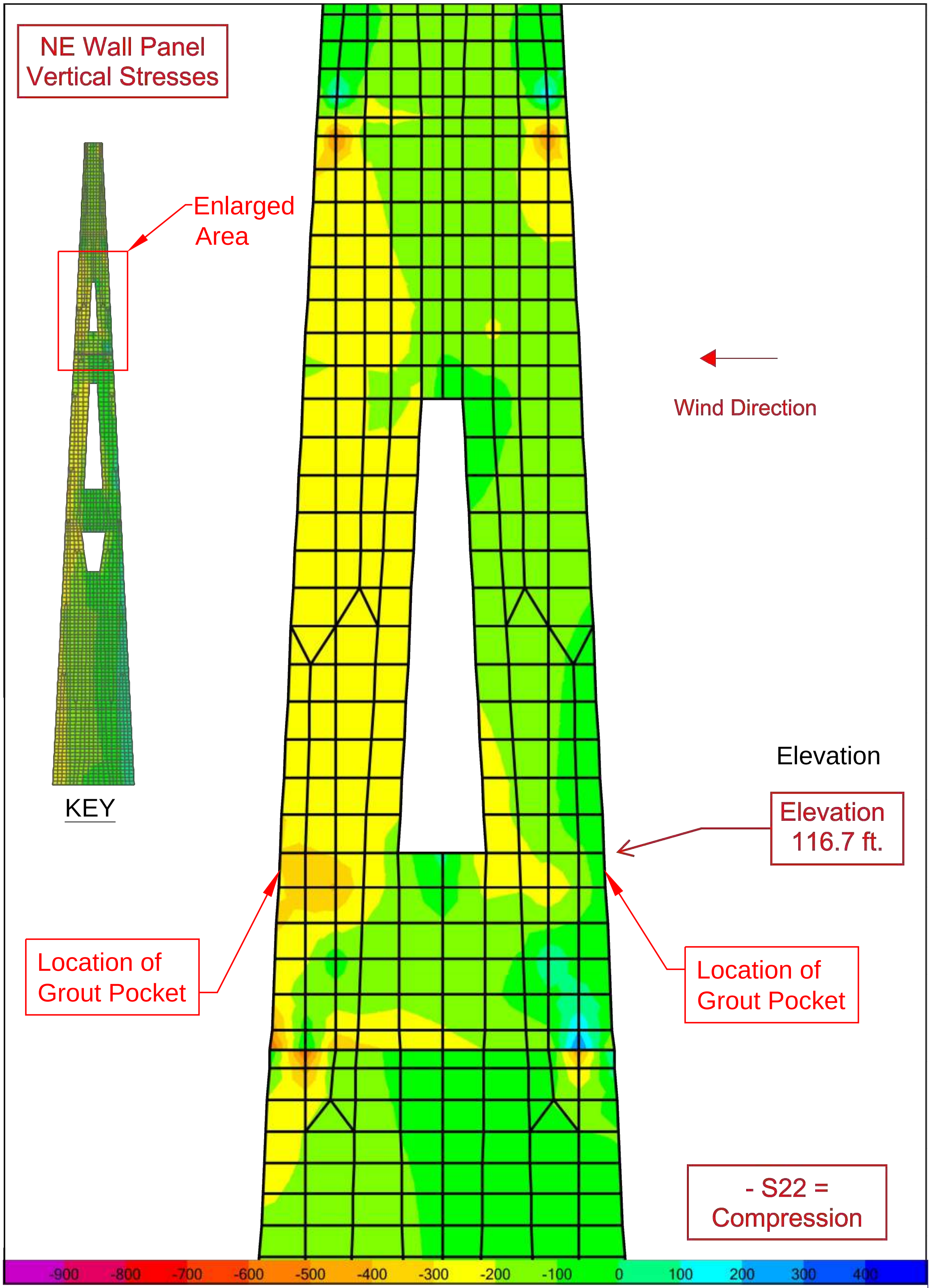
4
FIGURE

Tower07.sdb 11/15/2019



SAP2000 21.1.0 Stress S22 Diagram - Top Face (D+PT+W+X) lb, in, F

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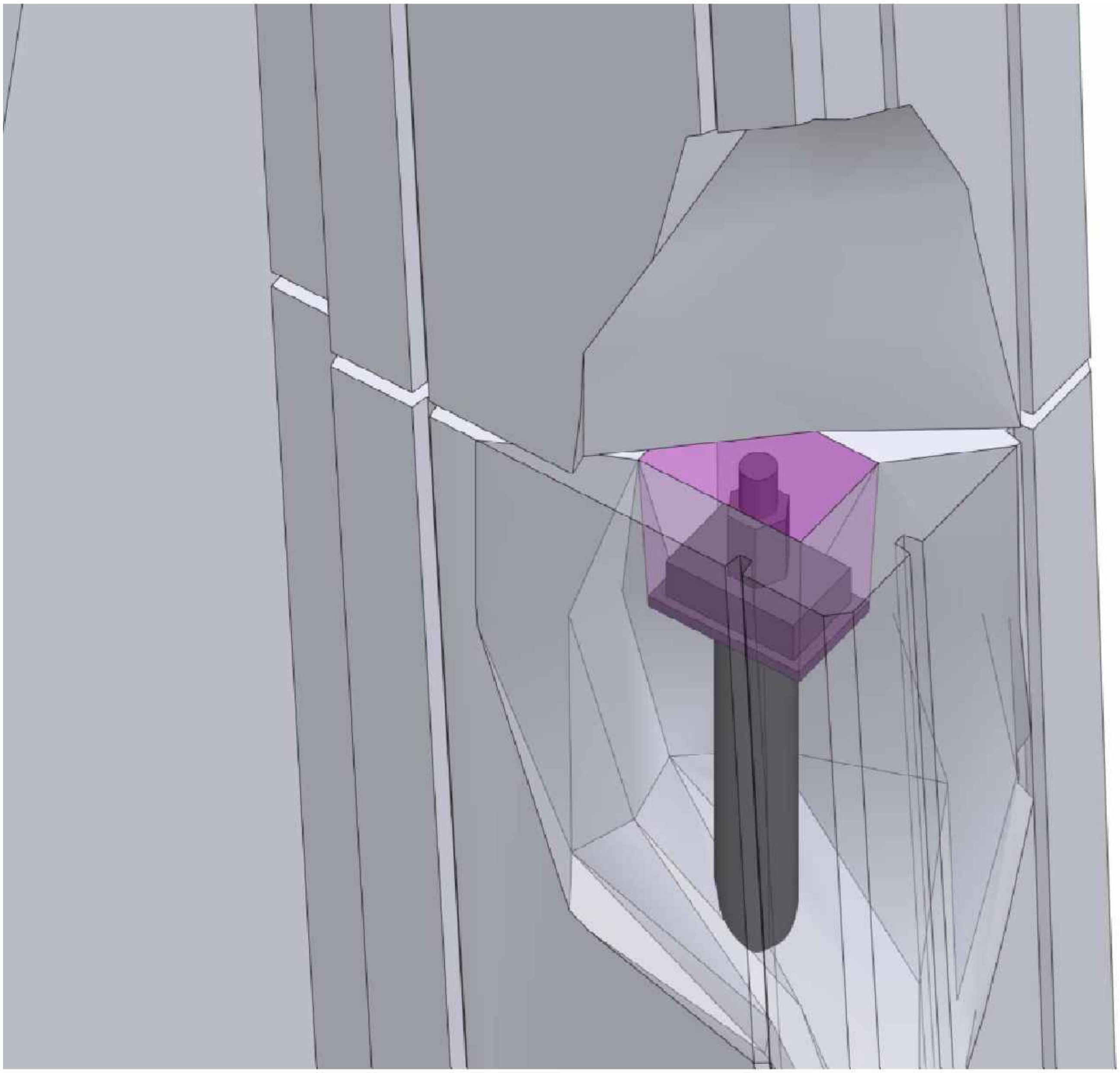

ISOMETRIC VIEW OF SPALLED GROUT
POCKET AND POST TENSIONING HARDWARE

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ENLARGEMENT OF GROUT POCKET
ERA - MOSER TOWER
NAPERVILLE ILLINOIS

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SCALE:	N.T.S.
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6
FIGURE