Robustness evaluation for condemned buildings and animated simulation of the collapsing elements

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Introduction

- The progressive collapse of building structures is initiated when one or more vertical load carrying members (typically columns) is removed. Once a column is removed due to a vehicle impact, fire, earthquake, or other man-made or natural hazards, the building's weight (gravity load) transfers to neighboring columns in the structure. The columns cannot resist and redistribute the additional gravity load, which means that part of the structure fails. The vertical load carrying elements of the structure continue to fail until the additional loading is stabilized.

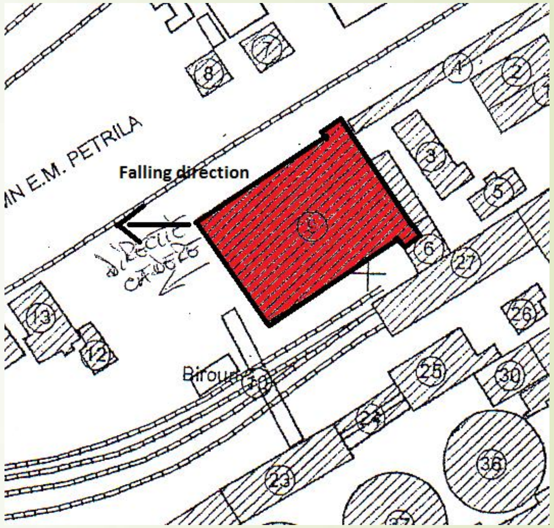
- As a result, a substantial part of the structure may collapse, causing greater damage to the structure than the initial impact

SCOPE AND OBJECTIVES

- The focus of this paper is to evaluate the robustness of a building condemned for demolition using software simulation. After all the failing elements have been identified an animation software is used to coarsely reproduce the collapse of the detached elements.
- The simulation was made using SAP2000 software, a powerful tool for hinged prediction. SAP2000 uses FEM(Finite element method) which is not as accurate and as practical as AEM(Active element method).
- In short, the purpose of all this is to determine the falling direction of the building and make sure no debris damage neighboring structures or infrastructure.

SITE LAYOUT AND DEMOLITION REQUIREMENTS

- The building in question is a depot/coal washing facility located in Petrila which has been abandoned after the coal mining industry declined in the early 90s.



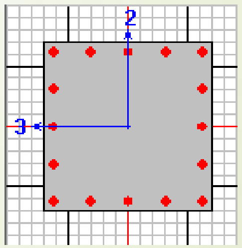
- The first problem the engineers on site faced, was collapsing only half of the building. This being the request of the owner.

- The second problem was making sure that the debris from the demolished building would never fall and damage the surrounding buildings and most importantly it could not disrupt or affect in any way the train tracks, especially since many carts and locomotives were stationed near by awaiting unloading.

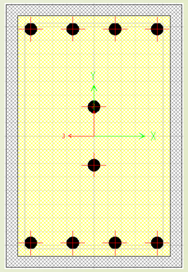
BUILDING DESCRIPTION

- The building is an irregular reinforced concrete frame structure with 8 stories having 7 openings of 5.5m and 9 spans of 6.3m having a total length of 39.3m over 57.5m. The top part is an annex which is 2 stories high distributed in a C shape.
- The technical documentation was not available, therefore an explosion test was done on one of the beams and columns for each section to determine the reinforcement.

Type of element	Dimensions	Location	Longitudinal reinforcement	Confinement bars	Concrete type
Column	120x120	Exterior, ground floor	20ø28 evenly distributed	20ø11, 25cm spacing	B350
Column	80x80	Interior floors 1-3	16ø28 evenly distributed	20ø11, 25cm spacing	B350
Column	70x70	Interior floors 4-8, annex interior 9-10	16ø34 evenly distributed	20ø11, 25cm spacing	B350
Beam	40x60	All floors	10ø28; 4 top; 4 bottom;2 upper and lower center(fig. 4)	25ø10, 25cm spacing	B300



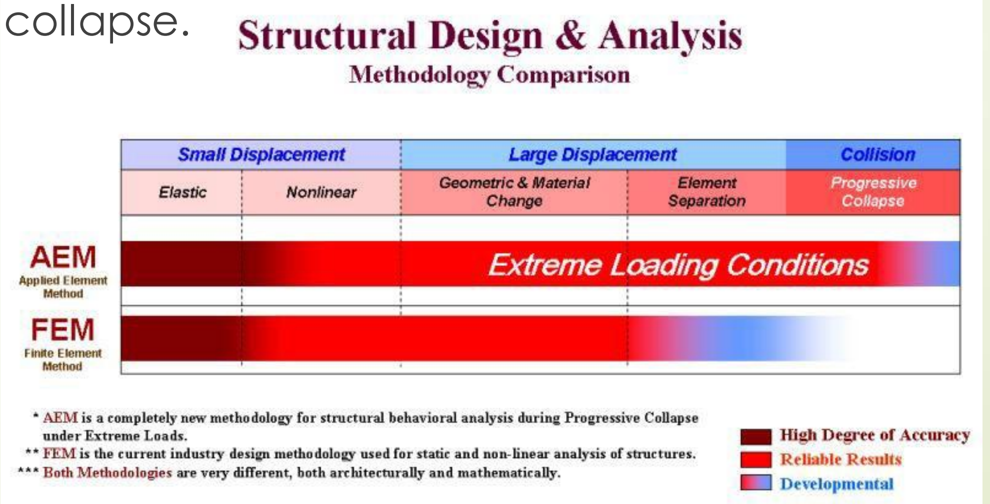
Column CS



Beam CS

Analysis method compassion AEM-FEM

- The main obstacle facing FEM when modeling structures is the modeling of large cracks and element separation. Although there are several FEM techniques that enable element separation, these are still limited to small problems with limited cracking and separation and cannot be generalized for use by practicing engineers in a full structural application.
- The main advantages of using AEM center around its ability to reliably and accurately predict structural behavior beginning with the initial loading stages, into crack initiation, through propagation on to complete collapse.



SAP2000 simulation

- For the simulation a static nonlinear analysis was conducted, using staged construction method. The building was divided in 6 groups. Group 1 to 5 were the columns that were rigged with explosives, whereas group 6 was the building without the columns from the above mentioned groups.
- For the staged construction load case, 6 stages were implemented. First the structure was added and then the load. In the second to the sixth stage each of the above mentioned 1 to 5 groups of columns were removed just like in the explosion stage scenario. This way the software can consider load redistribution and accurately compute element displacement.
- Resulting displacements were high, the structural elements located at the extremities were collapsing and due to FEM limitations the analysis was ending prematurely.

SAP2000 simulation

- To obtain data from all the affected elements in the structure, the dead load had to be reduced to a level were the strain from all the elements could be computed. The final reduction of the load was 70%.

- The external joints displacement values were monitored resulting in tow graphs Fig. A where the x-y displacement vector was created and Fig. B where one can follow the Z axis displacement of the node for each step.

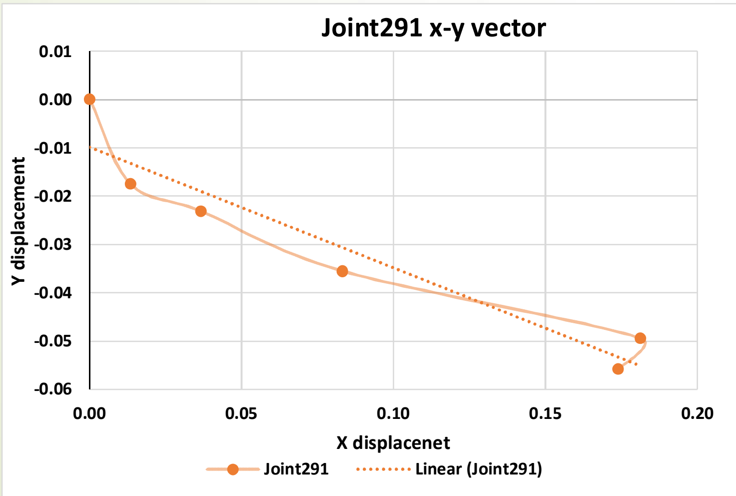


Fig. A

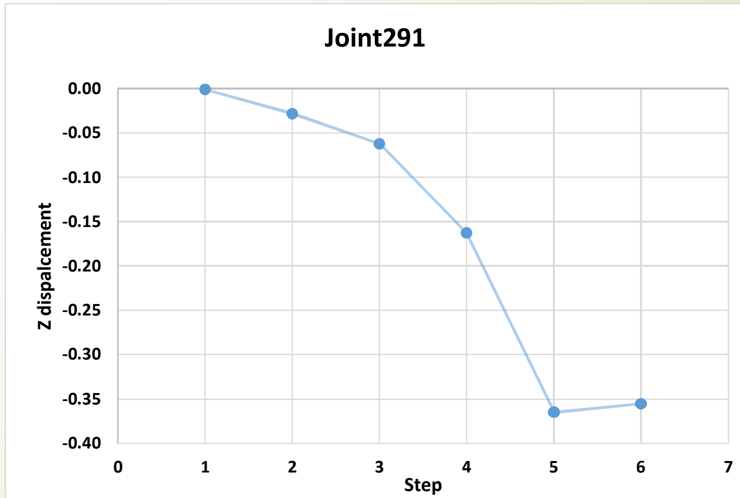
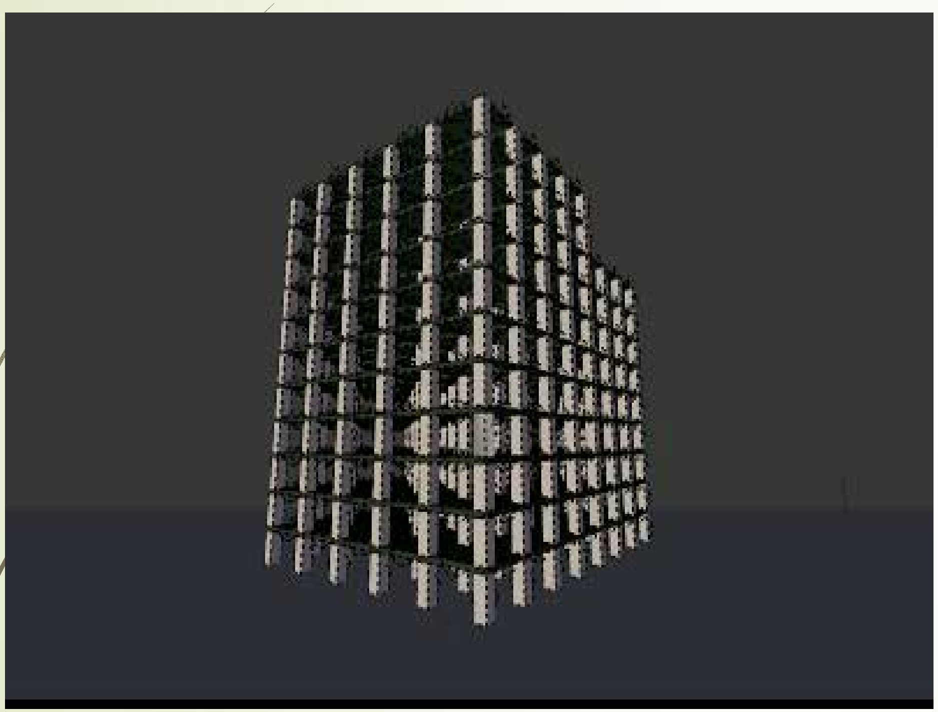


Fig. B

BLENDER ANIMATION

- Since FEM software can't reproduce the collapse animation of a structure, I have tried to do so with animation software.
- The only difference is that the objects in the animation do not break and the ones expected to collapse are not tied together since fracture is not calculated by the software at hand.
- Nevertheless, the end result matches the captured video on site with great detail. The explosion in the animation was not iterated. Moreover, just like in the SAP2000 simulation, the columns were removed in the same order with the 0.25s delay considered between detonation stages on site.

Head to head



The detonation did not occure according to plan. Certain exterior columns from the 3rd and 5th floor did not fail. Nevertheless the collapse direction was not altered.

CONCLUSIONS

- In an article publicized on the American institute of steel construction website from the University of Ohio, a researcher tested in the laboratory and ultimately on a live building how accurate a SAP2000 progressive collapse simulation can be. The difference in strain results was approximately 21%.
- To try and obtain a more accurate response, animation software was used to reproduce what would happen after the elements start collapsing and confirm if the estimated collapse direction is valid, or if certain unforeseen circumstances may change the outcome.
- The results were accurate, the structure behaved as expected. Small wedging affected some elements but it did not change the collapse angle.
- The demolition company considered this simulation a success.