Demolition of steel structures: structural engineering solutions for a more sustainable construction industry

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Abstract. This paper presents an introduction to structural demolition engineering as applied to steel structures. This work flows out of a research project aimed at providing design techniques for ensuring that structures can be both safely and efficiently demolished when they reach the end of their lifecycles. When a structure is to be demolished or imploded it is typically weakened such that when the collapse is triggered the collapse mechanism can be controlled and will occur as predicted. If structures are not weakened enough they may not collapse when required, but if weakened too much they could collapse prematurely killing demolition teams. This paper specifically discusses (a) a step-by-step analysis of the full-scale demolition of a large structure that the author filmed, explaining the structural mechanics of the system, and then (b) presents methods for weakening structures and how this influences failures. By providing verifiable methods for ensuring structural capacity, rather than relying on experience alone, the demolition process can become more efficient, leading to the increased recyclability of structures and a safer working environment.

Keywords: Demolition; steel structures; safety; structural engineering; weakening techniques; building recyclability.

1 Introduction

The demolition phase of a building is an important stage in its overall lifecycle. To enhance the sustainability of structures it is important the demolition can be carried out efficiently and safely, such that the maximum amount of material can be recycled. At Stellenbosch University various projects and publications have recently been completed on the behavior of steel structures during demolition by van Jaarsveldt, Walls & Dunn (2016; 2016; 2015; 2015), stemming from work started by Jet Demolition. Negligible research exists in the literature regarding structural

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engineering techniques that can be applied when designing buildings for demolition. Guidelines and even codes of practice exist in various countries for guiding the overall process (HK Bldg. Dept. 2004; IS 2002), although these typically note that competent engineers should carry out designs without necessarily providing details regarding how this can be done. In practice most contractors rely on years of experience, which is vital, but experience is seldom complimented by detailed calculation.

The majority of buildings are demolished using mechanical methods, and it is normally the exception to have implosions caused by explosives, although these are typically the type of demolitions covered in the media. Various methods exist for mechanical demolition including: the closed demolition method, cube cut method, reverse construction method, simultaneous dismantling, and the cut and take down demolition method, amongst others (JISF 2015). The author has been involved with projects where large chimneys, power station cooling towers, office blocks and other such structures were demolished. Structural designs for the aforementioned projects were typically developed based on first principle methods, along with significant factors of safety due to the high level of uncertainty regarding structural properties.

2 Case study

The figures below provide an understanding of the demolition process of a structure by considering a case study consisting of a large furnace. This structure was part of a very challenging project where the existing furnace shown had to be demolished within an operational factory, and a new furnace built in the same position, with the whole process needing to happen within around 3 months. Thus, the demolition team had to prepare and bring down the structure very quickly to allow for construction and mechanical teams to access the site. Figure 1 shows a plan layout of the structure. Mechanical demolition techniques were used with the columns and beams being weakened, and the overall process was carried out in three phases. The remaining figures and diagrams relate to the second phase of the process where the middle section of the structure was demolished. Phase 1 had previously been completed in a manner similar to that illustrated below.

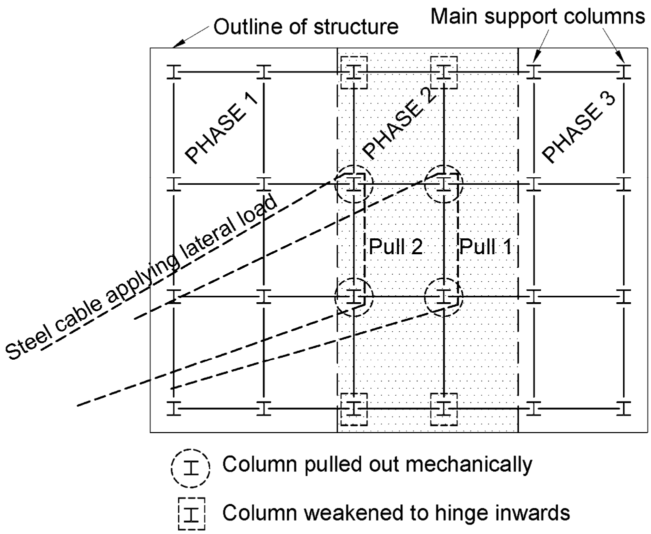

Fig. 1. Layout of furnace to be demolished, showing the phasing of the process

In Figure 2(a) the full structure is shown. The red circles indicate positions where the structure had been weakened. A layer of material around 1m thick had solidified in the furnace, providing a reasonable load on the weakened columns. It must be understood that up until this time teams had been working within this structure, which is potentially very dangerous if structures are weakened more than necessary, or if teams are inexperienced. Techniques for weakening structures typically vary, although in this case cutting torches were used to create holes in sections, or to fully cut members right through. The latter was used for the internal columns that were pulled out. Triangular cuts were used on the outer columns, whilst beams were either fully or partially cut through.

Once the structure was ready to be mechanically imploded a large construction vehicle was used to apply a lateral force to inner columns via a steel cable, as shown in Figure 2(b). The middle columns were prepared such that when this load was applied it caused column sections to fall out. The columns were pulled out by the cable in two steps, with the columns on the right of Figure 1 being removed first, “Pull 1”, followed by the second row of columns, “Pull 2”. The structure was left with sufficient integrity that when the first set of two columns was removed the structure still remained standing. When the second row was removed the collapse was triggered, as shown in Figure 3(a).

Fig. 2. (a) Furnace structure to be demolished. Red circles indicate where structure had been weakened; (b) Lateral load applied to structure to cause internal columns to pull out.

Fig. 3.(a) Structure in the process of collapsing after second line of columns removed;(b) Final pile of rubble which the demolition team could clear and recycle.

It can be observed that as the inner columns move downwards it pulls the upper components of the structure inwards. This ensured that the adjacent structure was protected and all material fell vertically. The resulting pile of rubble is shown in Figure 3(b). At this point in time demolition teams could access the rubble and recycle as much as possible. Once rubble had been cleared the next phase, Phase 3, of the demolition process could commence.

Bracing was left in the structure to provide stability until just prior to collapse when it was cut out. If needed bracing can be left in place to transfer load from one section of a structure to another, ensuring that portions are pulled over at certain times. When overall collapse is considered it is important that once a structure starts collapsing the momentum gained by falling components must be directed in the manner required. Falling material applies loads to any portion of the structure to which it is connected. Also, once columns are removed the load on the adjacent columns is instantaneously increased, so it must be ensured that they have sufficient reserves to carry additional force, or otherwise may inadvertently buckle. Overall it can be seen that the entire process illustrated above occurred quickly, whilst still being safe and allowed the rubble to be easily accessed and removed / recycled.

It was found that during the process one small portion of the structure did fall outwards due to the upper solidified layer providing more stiffness than expected. This slightly damaged an adjacent steel platform, which was quickly repaired. It should be understood that minimal data is typically available regarding structures to be demolished as they are old, have few extant drawings and often have unknown material properties. Hence, designs typically need to be very conservative, and allowance must be made for failures not happening exactly according to plan.

3 Techniques for weakening structures

Now that a basic introduction to the process has been provided it is important to consider how to weaken steelwork to ensure that collapses occur in the direction intended. Figure 4 shows some of the weakened techniques typically used in practice, along with finite element models of the cuts. In relation to the figure presented the following is shown: (a) the double window cut which is used in conjunction with explosives, (b) the triangular window cut which creates a hinge in a controllable manner, and (c) the circular window which provides a reduction in column capacity. Finite element modelling and full-scale tests carried out on such cuts have typically provided good estimates of column capacity prior to the onset of collapse.

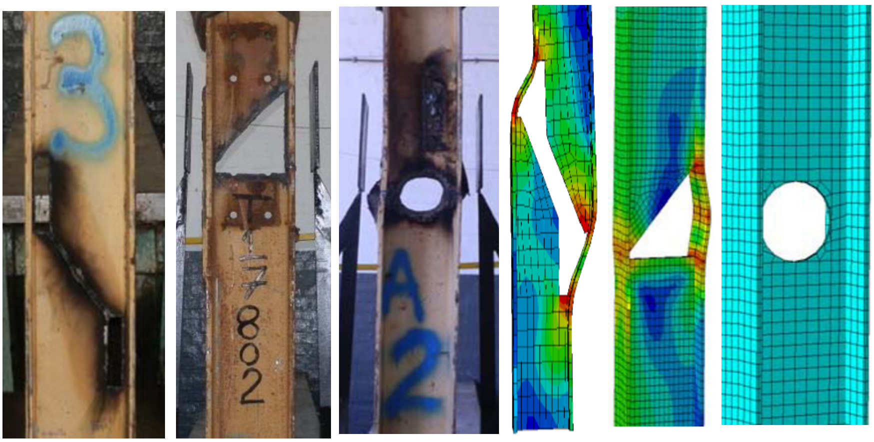

Fig. 4. Selected techniques for weakening columns: (a) double window cut used with explosives; (b) triangular window cut used to cause a hinge; and (c) circular window cut used for general weakening of structures, from van Jaarsveldt & Walls (2016).

It has been found from numerical modelling that the triangular window cut is typically the most predictable of all the cuts, and the flange on the right hand side fails as a mini column. Even though used in practice the circular window cut provides less reduction in capacity than would be expected as the overall buckling resistance of columns is not significantly affected. Often more than one cut is carried out on columns which makes behavior more difficult to predict, especially when slippage between elements occur.

For the internal columns of the furnace that were pulled out sections were cut through fully in the middle, and shims were used to ensure that load was still transferred. The cutting of columns must occur progressively, where after each small section is cut out steel shims are forced into the cut. Since load is still being carried by such columns friction forces exist which ensures that faces of cuts do not slip past each other. If multiple rows must be pulled out by a single cable it must be ensured that paths are created for the cable such that it does not get stuck or apply loads in the incorrect position. In addition to the full-depth horizontal cuts created in the columns that were pulled out additional cuts were created at the top and bottom of columns to create hinges when columns were pulled. The determination of the magnitude of lateral load required to induce collapse is a topic for future research.

4 Conclusions

This paper has provided an overview of the mechanical demolition process by investigating step-by-step the demolition of a furnace. The structure was initially weakened using a cutting torch and then collapse was induced through the application of a lateral load. A thorough understanding of structural mechanics is required to carry out such projects, although structures being demolished can still be unpredictable.

It is important that teams bring down structures in ways that allow the maximum amount of material to be recycled. Furthermore, for the construction industry to be sustainable working practices must be safe. By developing methods for calculating the capacity of structures safety can be more readily ensured.

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