COST C26 – WG3

Datasheet no….

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EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS ON THE BEHAVIOUR OF BUILDING FRAMES FURTHER TO A COLUMN LOSS

Keywords

- Loss of a column, experimental test, analytical investigation, membranar effects, beam-to-column joint behaviour

Description

- In (Demonceau, 2008), the behaviour of steel and composite building frames further to a column loss, when significant membrane effects developed within the structure, is investigated.
- Main objectives:
  - To identify the parameters influencing the response of a structure further to a column loss;
  - To validate analytical and numerical tools requested to perform the different investigations;
  - To develop a simplified analytical method able to predict the response of a frame further to a column loss, taking into account the redistribution of the loads within the structure.
- To achieve these goals, analytical, numerical and experimental investigations have been conducted. In particular, an experimental test on a substructure simulating the loss of a column in a composite building frame have been performed at Liège University, as part of a RFCS European project titled “Robust structures by joint ductility” (Robustness, 2008).

Field of Application

- The conducted investigations are dedicated to the behaviour of steel and composite frames further to a column loss.
- The presented studies are limited to the investigation of the response of 2D structures, i.e. the 3D effects which could influence the structural response (as the presence of secondary beams perpendicular to the considered plane or the distribution of the loads within the 3D slab) are not considered.
- Within the presented developments, it has been assumed that the action leading to the column loss does not induce significant dynamic effects; so, the performed investigations have been funded on static approaches. Accordingly, the column has been assumed to be progressively removed from the frame and the normal load within this column varies progressively from the one appearing under the loads applied to the structure just before the occurrence of the exceptional action to 0 when the column is completely removed from the frame.

Structural aspects

- When a structure is losing a column, the latter can be divided in two parts as illustrated in Fig. 1:
  - The directly affected part which represents the part of the building which is directly affected by the loss of the column, i.e. the columns, the beams (with the beam-to-column joints at their extremities) which are just above the loss column;
  - The indirectly affected part which represents the rest of the building which is affected by the loads developing within the directly affected part and which influences the development of these loads.
- In Fig. 2, the curve representing the evolution of the normal load in the loss column according to the vertical displacement at the top of the loss column Δ_a is illustrated. Three phases are identified on this curve:
  - At point (1), the frame is not loaded; so, N_{lo} and Δ_A are equal to 0.
  - From point (1) to (2) (Phase 1), the design loads are progressively applied, i.e. the “conventional” loading is applied to the structure; so, N_{lo} progressively decreases (N_{lo} becomes negative as the column “AB” is subjected to compression) while Δ_A can be assumed as equal to 0 during this phase (in reality, there is a small vertical displacement at point A associated to the compression of the columns below point “A”). It is assumed that no yielding appears in the investigated frame during this phase, i.e. the frame remains fully elastic.
  - From point (2) to (5), the column is progressively disappearing. Indeed, from point (2), the compression in column “AB” N_{lo} is decreasing until reaching a value equal to 0 at point (5) which means that the column can be considered as fully destroyed. So, in this zone, the absolute value of N_{lo} is progressively decreasing while the value of Δ_A is increasing. This part of the graph is divided in two phases as represented in Fig. 2:
    - From point (2) to (4) (Phase 2): during this phase, the directly affected part passes from a fully elastic behaviour (from point (2) to (3)) to a plastic mechanism at point (4). At point (3), first plastic hinges are appearing in the directly affected part.
    - From point (4) to (5) (Phase 3): during this phase, high deformations of the directly affected part are observed and second order effects play an important role. In particular, significant catenary actions are developing in the bottom beams of the directly affected part.
- It is only possible to pass from point (1) to (5) of Fig. 2 if:
  - the loads which are reported from the directly affected part to the indirectly affected part do not induce the collapse of elements in the latter (for instance, buckling of the columns or formation of a plastic mechanism in the indirectly affected part);
  - the compression loads appearing in the upper beams of the directly affected part (associated to an “arch” effect) do not lead to the buckling of the latter;
  - if the different structural elements possess a sufficient ductility to reach the vertical displacement corresponding to point (5).

- As mentioned previously, the investigations conducted in (Demonceau, 2008) are dedicated to the behaviour of a frame when significant membrane effects developed within the latter, i.e. during Phase 3 of Fig. 2. The behaviour of the structure during the other phase is the topic of another thesis (Luu, 2008) to be presented end of 2008.

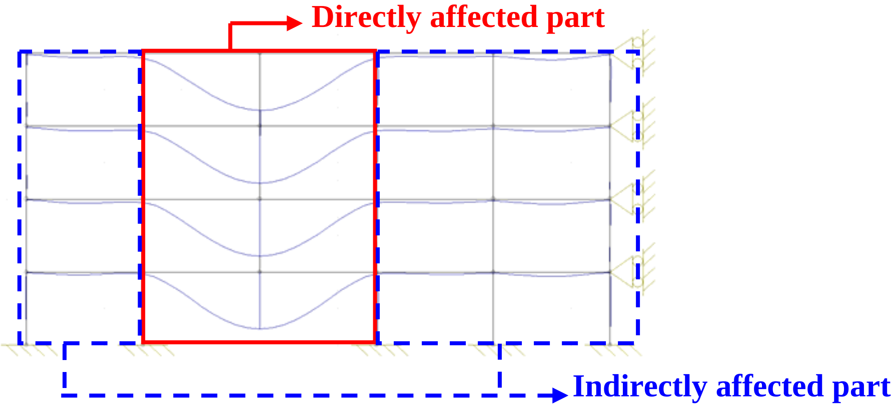

Figure 1. Definition of directly and indirectly affected part

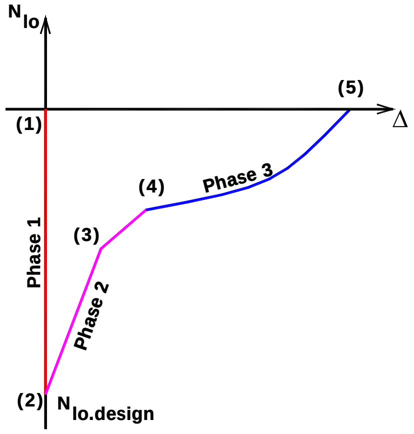

Figure 2. Evolution of the axial load in the loss column according to the vertical displacement at its top

Research activities

- Analytical, numerical and experimental activities have been conducted to investigate the behaviour of a frame further to a column loss when significant membranar forces developed. The latter are described here below
- An experimental test on a substructure simulating the loss of a column in a composite frame has been conducted at Liège University. The main objectives were:
  - To observe the development of membranar effects within structural beams;
  - To observe their effects on the behaviour of structural beam-to-column joints;
  - To collect the requested information to validate later on developed and/or used analytical and numerical tools.

  The tested substructure and the obtained results are described in details in (Demonceau, 2008).
- Then, analytical and numerical tools were validated. In particular:
  - The homemade finite element software FINELG was validated through comparisons to the experimental results obtained for the substructure test and

    through a benchmark study realised within the RFCS project Robustness (Robustness, 2008).

    - An analytical method able to predict the resistance of beam-to-column composite joints subjected to combined bending moments and axial loads, situation not yet accurately covered within the actual codes and standards, have been developed and validated through comparisons to experimental tests obtained at Stuttgart University, as part of the RFCS project Robustness (Robustness, 2008). The developed method is funded on the one initially developed for steel joints within the PhD thesis of Cerfontaine (Cerfontaine, 2003). This method is in full agreement with the component method which is the method recommended for the joint design in the Eurocodes.

- With the so-validated tools, it was possible to define and to validate (through numerical investigations) a simplified substructure modelling able to accurately predict the response of the directly affected part (see Fig. 1) during Phase 3 (see Fig. 2). This substructure modelling is presented in Fig. 3.

  Within the simplified substructure, the properties of the beams and of the joints at their extremities are the ones of the bottom storey of the directly affected part. The influence of the indirectly affected part on the response of the directly affected part is taken into account through an horizontal spring with a stiffness K and a resistance F_{Rd}. The effect of the column loss is simulated through the concentrated load Q. The properties of the horizontal spring (i.e. K and F_{Rd}) and the concentrated load Q to be supported during Phase 3 can be determined through analytical procedures proposed in (Luu, 2008).

- Finally, a simplified analytical procedure has been developed in (Demonceau, 2008) to predict the response of the so-defined simplified substructure modelling when significant membrane forces developed within the system.

  The proposed analytical method is funded on a second-order rigid-plastic analysis; so, it is assumed that the deflection of the substructure is developing when a plastic mechanism is formed within the system. This method takes into account of:

  - the effects of the indirectly affected part (simulated through the horizontal spring);
  - the M-N interaction at the plastic hinge level (developing in the beams or in the partial-strength joints);
  - the elongation of the plastic hinges associated to the development of the catenary action.

  The analytical method has been validated through comparisons with the experimental results obtained for the substructure test as illustrated in Fig. 4 representing the evolution of the vertical deflection of the tested substructure at the column loss level (Point A in Fig. 4) according to the applied load.

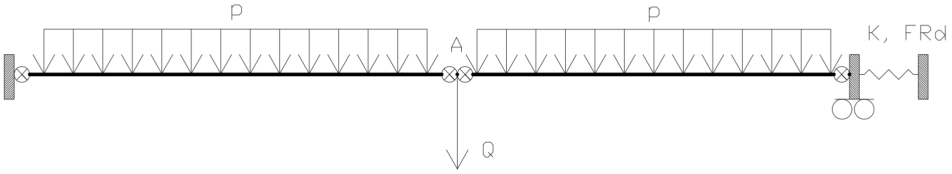

Figure 3. Defined substructure modelling able to simulate the response of the directly affected part during Phase 3

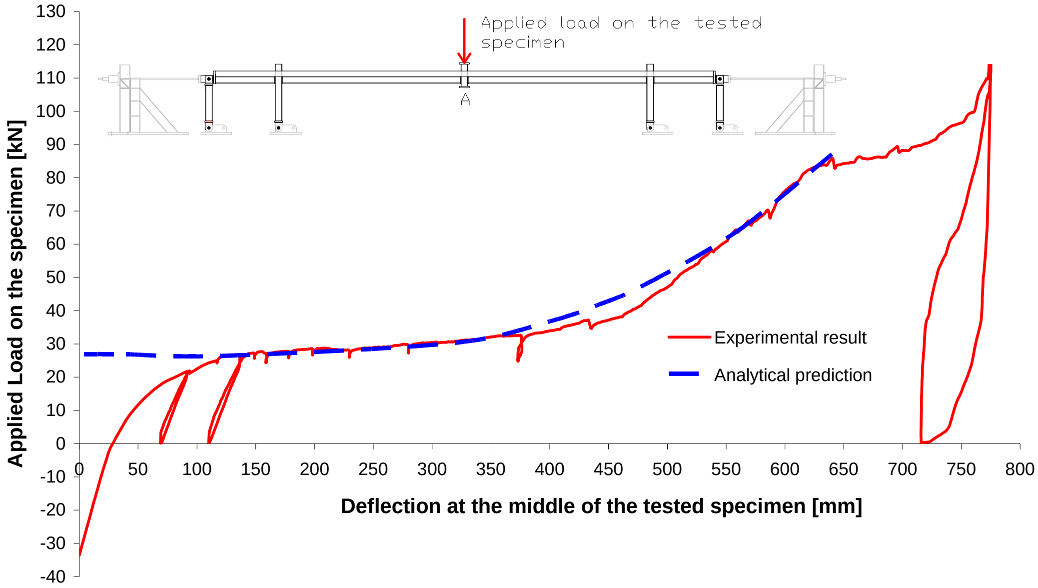

Figure 4. Comparison analytical prediction with the proposed method vs. Experimental resutls obtained through the substructure test

Further developments

- As mentioned previously, all the performed developments are funded on a static approach. In a near future, investigations will be conducted to study the dynamic effects which could be associated to a column loss and to include them in the developed analytical methods.
- Only the 2D behaviour of structures has been considered in the presented developments. Further investigations should be performed to investigate the 3D effects which could influence the structural response of the building.
- Through the numerical investigations conducted in (Demonceau, 2008), the difficulty to simulate accurately the actual behaviour of joints subjected to combined bending moments and axial loads has been illustrated. The development of a finite element able to simulate their behaviour is requested and should be the scope of further developments.
- What has been developed in (Demonceau, 2008) and (Luu, 2008) are direct methods of design for frames subjected to the exceptional event “loss of a column”. The next step will be to derive, from these direct methods, easy-to-apply design guidelines (i.e. simple rules which are easy to use by practitioners in design offices) which could ensure an appropriate robustness to a building when subjected to such an exceptional event.

References

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