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5. Discussion of IABSE PROCEEDINGS «Dynamic Analysis of Steel Structures with Regard to Progressive Collapse» U.A. Girhammar and L. Östlund, published in May 1987 in IABSE PERIODICA 2/1987

A Discussion by G.S.T. Armer, UK

Professors Girhammar and Ostlund have produced an interesting paper on trhe behaviour of steel structures. By their very nature, however, large structures constructed of many elements will not be overloaded uniformly all over, but locally, except in the special cases of earthquake, hurricane/typhoon and possible occasional instances of subsidence. It is therefore logical to assess the potential behaviour of such large structures when they suffer a local failure from whatever cause.

Progressive collapse is, as its title implies, collapse which progresses; unfortunately none of the examples discussed in this paper can be so described and, in consequence, the «fundamental measures to assure structural integrity...» are not necessarily sufficient or appropriate for cases where progressive collapse is a possible failure mode. The three measures identified by the authors are:

1. excess strength
2. redundancy
3. large deformation capacity

Actual failures attributed to these three aspects are briefly discussed below.

1. excess strength

The failure of the garage floors in the Skyline Plaza [1] (a 2 storey cast in situ structure) collapse was entirely dependent upon the high in-plane strength of the slabs. Once the column punching failure started, horizontal integrity of the slabs was required to transfer loads from each failed column/slab connection to its neighbours and hence allow the collapse to progress across the slabs. The only way to prevent this form of horizontal load transfer is to have breaks in the horizontal reinforcement of such slabs and to allow the structure to shed loads i.e. the horizontal integrity must be locally weakened.

2. redundancy

The assembly hall roof at Camden School [2], a precast concrete beam structure, had structural connection in the roof cladding normal to the direction of span of the beams. When one beam support failed, the load was transferred to its neighbour which also failed and so on. Thus, in this case, the redundancy was the **essential** element of the structure which facilitated the progressive collapse.

3. large deformation capacity

In the Ronan Point failure [3] and other [4] cases connections were ductile in the sense used by the authors and failure still occurred. The movements involved in the progressive failure of complex structures are far greater than any ductility available in practical structural elements for joints. Ductility may, however, be useful in the control of local failures.

Progressive collapse in a structure involves a failure front which moves away from an initial local failure i.e. the trigger, to envelope portions of the structure much lager than the trigger zone. The front is mobilised by the conversion of the potential energy of the structure into kinetic energy. The direction and extent of a progressive collapse will depend upon structural form, i.e. the disposition of structural materials in the building and the pattern of weak and strong zones/joints, the location of the accidental local failure and the ease with which the potential energy of the building can be released to propagate the failure front.

As shown above, the views promoted in the paper are not sufficient to form an adequate design philosophy for structural design, and would lead to the construction of dangerous buildings vis à vis their response to local failure.

The authors might wish to consider strategies which are described elsewhere [5].

References

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3. Report of the Inquiry into the collapse of flats at Ronan Point, Canning Town. H.M.S.O., U.K. 1968.
4. Armer, GST. Dynamic tests on a multi-storey model. Proc. RILEM–CEB. CIB Symposium, 1978.
5. Armer, GST. The stability of large structures. Building Research and Practice. July/August 1983.

Reply of the Authors to Mr Armer's Discussion

We thank Mr Armer for his discussion on our paper. His discussion makes it possible for us to set out our view on general design principles for damage tolerance of all kinds of structures and not restrict ourselves to the multi-storey steel framed structures discussed in our paper.

Mr Armer states that:

- none of the examples discussed in our paper can be described as examples of progressive collapse; and
- our views on the fundamental measures to assure structural integrity are not sufficient and not even appropriate to form an adequate design philosophy for structural design of cases where progressive collapse is a possible failure mode.

Our objective in the paper was not to discuss the mechanisms of the progressive collapse themselves but rather how to stop the local damage from progressing outside the area of primary damage. There are two ways to control local failure:

(I) Assure structural integrity and damage tolerance of buildings by the three measures 1. excess strength, 2. redundancy and/or 3. large deformation capacity. This approach must include the design of the remaining structure so that it can absorb the additional forces imposed on it due to the local failure and check the over-all stability of the structure (cf. page 76 in our paper: «The boundary forces must in a second step, be transferred to the remaining part of the structure and the over-all stability of the structure must be checked»).

(II) Assure that local damage can occur without involving a large part of the remaining structure.

This approach implies the design of the structure with locally weakened structural integrity and continuity.

We think that both approaches are applicable in the general case and that the designer must choose beforehand which road to take. The applicability of the different approaches depends primarily upon:

- the kind of structure and the structural system being used; and
- the acceptable size of the final damage resulting from the local failure.

We think that the first approach should be applied to structures which are characterized by inherent excess strength, continuity and ductility, e.g. steel-framed structures, where it would be natural to add the damage tolerance design to those properties, to structures which are designed with multiple «units», e.g. multistorey buildings, for which the final damage will be too large (e.g. comprise a whole section according to figures 1b and 8 in our paper) if you do not control the local failure; and to structures braced by plate action in wall and floor components, e.g. steel-framed structures with monolitic concrete slabs, which are structural systems which have a great potential to absorb additional actions and remain stable.

The second approach or some other special considerations, we think, should be applied to single-storey-, single-span-, and single-«unit»-type structures, e.g. factory buildings, for which the primary load-bearing system comprises more or less the whole structure and, therefore, do not have a surrounding structure, at least not in the full sense discussed above, to which the additional forces can be transferred, and for which damage that will comprise the whole «unit» is not acceptable; and to the type of structures that do not have shear walls for bracing purposes, e.g. parking decks, for which the lack of horizontal stiffness will not make it possible to confine the effects of the local failure on the remaining structure to the immediate surrounding area.

The Skyline Plaza and Camden School examples discussed by Mr Armer fall in the categories of column-deck structures and factory-type buildings. We agree that that kind of structure should be designed according to the second approach or at least require some other special considerations not treated in our paper. The Ronan Point building did **not** have ductile connections in the sense used by us in our paper. The kind of ductility we are

Large panel building in Algeria, Granström & Carlsson (1974). An explosion in the ground floor caused considerable damage in the panel structure without damaging the elements above.

discussing is like the earthquake-resistant building in Algeria which has strong connections between its panels, see figure below /7/. An explosion in the corner flat on the ground level caused local damage but there was no spread throughout the building. The scope of the final damage was limited in this case. In the case of Ronan Point the extent of the final damage was unacceptable.

In conclusion, we find that Mr Armer draws attention to an important aspect of the design of structures with regard to progressive collapse, but that that aspect is not quite relevant to the kind of structure and conditions we are discussing in our paper. Our view is that there are at least two approaches to the damage tolerance design of structures and that the one that is adequate in the actual case depends on the kind of structure the kind of structural system used and the potential damage conditions. We think that the multi-storey steel-framed structures we are discussing should be designed in a different way than the factory-type and column-deck concrete structures Mr Armer is discussing. This means that we agree that the fundamental measures to assure structural integrity and damage tolerance of structures are not applicable to all kinds of structures but that they are appropriate for the kinds of structures we are discussing.

We realize, though, that it would have been an advantage had we presented both aspects (the approaches) more explicitly in our original paper. Hopefully, we have now clarified ourselves concerning that matter in this reply to Mr Armer's discussion.

ERRATA:

IABSE PROCEEDINGS P–111/87, page 76, line 14 from above

Reads: «In the **second** step the floor structure...»

Should read: «In the **first** step the floor structure...»