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Interaction Analysis of Asymmetric Sway Frames

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A novel method is presented for the approximate three-dimensional analysis of asymmetric sway frames subjected to torsional loading causing P-Delta effects.

The two most significant aspects of the new procedure are:

1. That actual structures need not individually be analysed on a rigorous elastic-plastic basis but by using their elastic buckling load and rigid plastic collapse load as reference parameters i e similar to the conventional in-plane analysis of single columns without the need for iterations.
2. That the proposed method can be used on a story-by-story basis for multi-story structures, thereby greatly reducing the number of variables compared with an investigation of the full frame. The load factor of the weakest story is then taken as the load factor applicable to the entire framework. More details and the principles of the new analysis technique are given in Refs.1-4.

The technique is suitable for three-dimensional frame structures made up of intersecting rectangular grids, ignoring local and torsional buckling of the members and disregarding their torsion and warping resistances.

The fundamental assumptions can be summarised as follows:

1. Any given frame structure can be grouped into a unique family of frames.
2. Each family of frames can be represented by a specific curve in a multicurve interaction graph.
3. The significant frames within a particular family of frames are a frame unaffected by P-Delta effects for which the failure load is equal to its rigid-plastic collapse load and a frame that fails completely elastically, i e failure is related to elastic buckling. The latter frame is termed the "limiting frame" of the frame family.
4. Between the two significant frames other frames can be located on the failure curve by reference to their ratio of elastic buckling load to rigid-plastic collapse load.

The presence of torsion is recognised by examining rigid-plastic collapse modes and elastic buckling modes in both directions of the rectangular frame grid and by elastically distributing the total applied lateral load to the individual frames on the grid when it comes to defining the geometry of the "limiting frame". The parameter $(0{,}4P_C/P_P)_\ell$ of the "limiting frame" is used to select the relevant curve from the multicurve diagram. The actual structure is then located on that curve by its ratio $0{,}4P_C/P_P$.

The establishment of the "limiting frame" is thus of prime importance when obtaining the failure load from the interaction graph. In its simplest format the ratio $(0{,}4P_C/P_P)_\ell$ of the "limiting frame" can be found from the equivalent ratio applicable to the actual structure, i e $0{,}4P_C/P_P$, by using Eq.(1) which is derived by equating elastic failure and first yield.

$$\left(\frac{0{,}4P_C}{P_P}\right)_\ell = \frac{0{,}4P_C}{P_P}\,\frac{Zf_P}{M}\,R \qquad \text{Eq.(1)}$$

To solve Eq.(1) the actual structure is subjected to loading of the same configuration as the factored applied load but in magnitude related to the elastic buckling load of the frame. The parameter Z is the elastic section modulus, M=second-order elastic moment, f_P=stress at onset of yield. The factor R recognises that the reduction to the fully-plastic moment capacity of column sections due to axial load and bi-axial bending may be different for the actual and the "limiting frame". The value R can often be estimated, however, R=1 will mostly give satisfactory results. For the structure under consideration the lowest ratio $(0{,}4P_C/P_P)_\ell$ is significant.

The presented method compares well with experimental and rigorous analytical results. A single-story model framework subjected to torsion was recently tested by the author. The experimental failure load exceeded the predicted value by less then three per cent.

The shown multi-story structure is similar to a framework previously analysed by Hibbard and Adams(5). The lowest story load factor for proportionate vertical and horizontal loading is found as 0,95.

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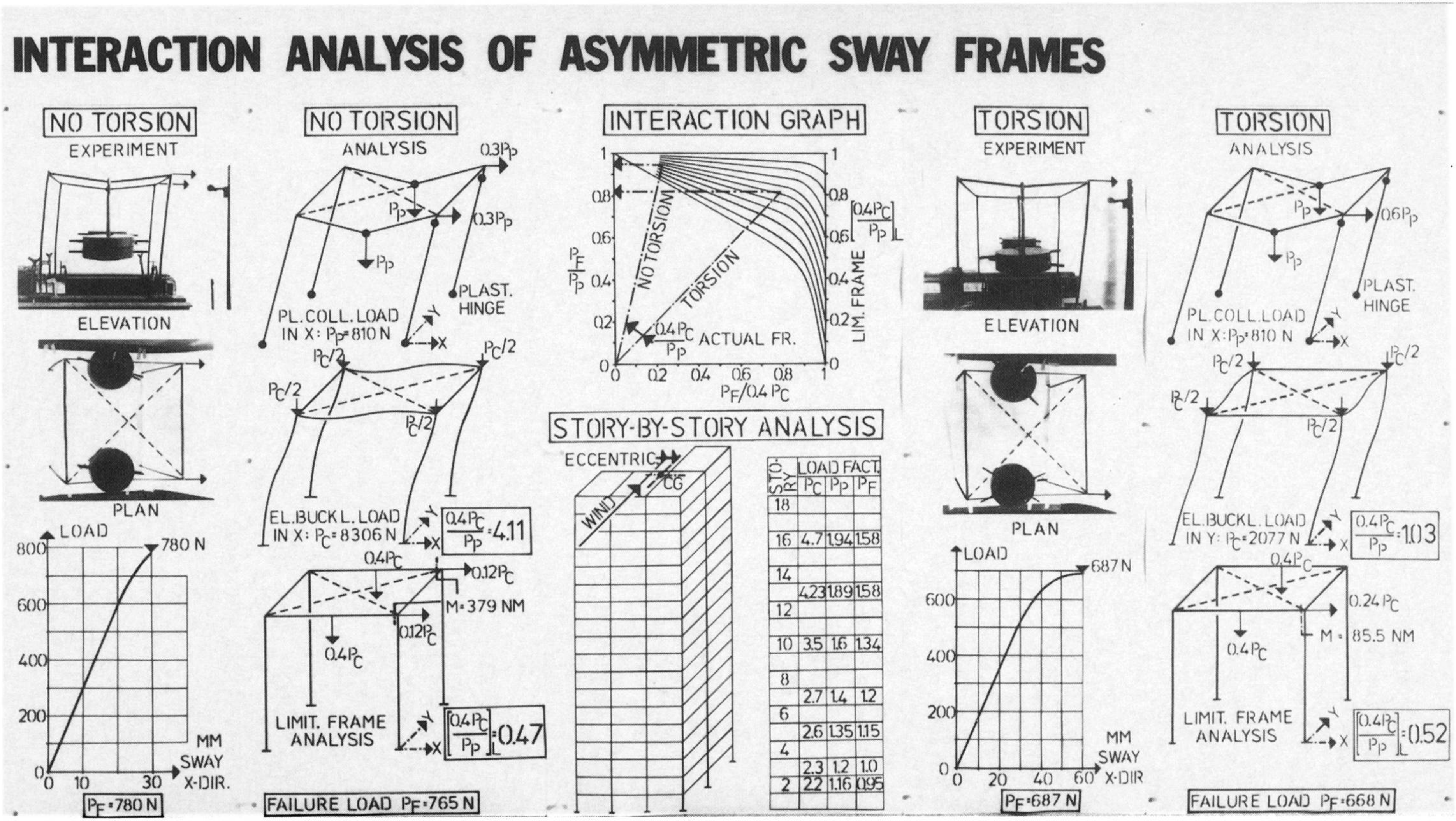
INTERACTION ANALYSIS OF ASYMMETRIC SWAY FRAMES
NO TORSION
EXPERIMENT
ELEVATION
PLAN
LOAD
780 N
MM SWAY X-DIR.
P_F = 780 N
NO TORSION
ANALYSIS
$0.3P_P$
P_P
PL. COLL. LOAD IN X: P_P = 810 N
PLAST. HINGE
$P_C/2$
EL. BUCKL. LOAD IN X: P_C = 8306 N
$\frac{0.4P_C}{P_P} = 4.11$
$0.4P_C$
$0.12P_C$
M = 379 NM
LIMIT. FRAME ANALYSIS
$\left[\frac{0.4P_C}{P_P}\right]_L = 0.47$
FAILURE LOAD P_F = 765 N
INTERACTION GRAPH
$\frac{P_F}{P_P}$
$P_F/0.4P_C$
NO TORSION
TORSION
$\frac{0.4P_C}{P_P}$ ACTUAL FR.
$\left[\frac{0.4P_C}{P_P}\right]_L$ LIM. FRAME
STORY-BY-STORY ANALYSIS
ECCENTRIC
WIND
CG
STORY | LOAD FACT. P_C P_P P_F
18
16 4.7 1.94 1.58
14
4.23 1.89 1.58
12
10 3.5 1.6 1.34
8
2.7 1.4 1.2
6
2.6 1.35 1.15
4
2.3 1.2 1.0
2 2.2 1.16 0.95
TORSION
EXPERIMENT
ELEVATION
PLAN
LOAD
687 N
MM SWAY X-DIR
P_F = 687 N
TORSION
ANALYSIS
$0.6P_P$
P_P
PL. COLL. LOAD IN X: P_P = 810 N
PLAST. HINGE
$P_C/2$
EL. BUCKL. LOAD IN Y: P_C = 2077 N
$\frac{0.4P_C}{P_P} = 1.03$
$0.4P_C$
$0.24P_C$
M = 85.5 NM
LIMIT. FRAME ANALYSIS
$\left[\frac{0.4P_C}{P_P}\right]_L = 0.52$
FAILURE LOAD P_F = 668 N