

DAMAGE CONTROL IN NEW ZEALAND PUBLIC BUILDINGS THROUGH SEPARATION OF NON-STRUCTURAL COMPONENTS

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1.0 SYNOPSIS

Rigid non structural components in N.Z. public buildings have for over 10 years been detailed to be separated from the structures. The justification, objects and design basis for this damage control strategy are discussed in the light of recorded earthquake damage. Practical details for connections of exterior pre-cast panels, curtain walls, partition and stairs are given. Economics are briefly discussed and also the problem of how to implement the designers aims successfully on site.

2.0 INTRODUCTION

Prior to about 1960 our understanding of building behaviour in earthquakes was limited and designers efforts therefore had to be concentrated on achieving structural survival. Fortunately most buildings were then relatively rigid shear wall type buildings which possess significant built-in damage control. In recent years a demand for higher buildings with an open floor plan and exterior claddings of glass and/or pre-cast concrete resulted in frame structures of totally different earthquake response characteristics. Theoretical considerations supported by evidence from earthquake performance indicate that this type of building, notwithstanding the usually longer fundamental period suffers large displacements in earthquakes. For reasons of safety, long term economy and avoidance of the possible total disruption of a small country's infrastructure effective antiseismic measures, including the separation of components, are required in these structures.

3.0 EVIDENCE FROM RECENT EARTHQUAKE DAMAGE

The need for damage control measures is strongly supported by evidence from earthquake damage which clearly indicates that non-structural damage may involve a high degree of life hazard.⁽¹⁾ Examples are failures of exterior pre-cast concrete panels, masonry infilling walls and partitions, particularly around stairs and means of egress. Non-structural elements can and have resulted in the failure of the primary system by inducing accidental torsions, by causing column sway mechanisms to form due to unintended changes in storey stiffness, or by concentrating excessive shears in a few columns, stiffened and made less ductile by part-height partitions.

4.0 RESPONSE OF BUILDINGS

The strong response of modern structures observed in earthquakes⁽¹⁾ is readily explained by analytical methods. Not surprisingly therefore even fairly stringent code requirements⁽⁶⁾ are adequate for moderate intensities only⁽⁹⁾⁽¹⁾ e.g. $\frac{1}{2}$ the ultimate code design earthquake for short period R.C. structures.

5.0 DAMAGE CONTROL STRATEGIES

Since structure deformation is the most important single cause of damage to components its reduction must be the first aim. Deformation may be reduced by decreasing displacement response of a structure and/or by increasing a structure's stiffness. Methods of decreasing the response such as the use of base isolation devices⁽⁴⁾ hold much promise but are still under development. The stiffness of structures may be effectively increased

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by the use of adequate shear walls or by using such devices as "Muto slit" walls, etc. If none of the above approaches are adequate or suitable, components should be separated.

6.0 OBJECTIVES OF THE SEPARATION OF NON-STRUCTURAL COMPONENTS

With particular reference to public buildings the objective is to: avoid damage in moderate earthquakes, limit damage in severe earthquakes to allow the building to be used for its required function during and following a disaster and prevent non-structural components from unfavourably altering the intended performance of the structure. Detailing should be such that if damage does occur, restoration can be carried out readily.

7.0 DEFORMATION OF TYPICAL N.Z. PUBLIC BUILDINGS

To obtain the deformation values which are of greatest significance in the design of cladding details some recently designed R.C. Public Buildings were analysed using the Drain 2-D computer programme and a number of earthquake inputs. The results are shown in figs 1a-1d. The deformation values are relatively low because NZS:4203 design procedures lead to stiff structures. Fig 1b applies where panels are essentially fixed at their lower edges and free to slide at the top. For more flexible buildings e.g. structural steel, the possibility of damage due to panel rotation must be considered. The value of Δ_r (fig 1b) for a frame of max. allowable code flexibility ($13 \text{ mm} = \Delta_s = 0.004 \times \text{storey height for } 15.6\% \text{ horizontal load}$) is 11 mm for a 3.4 m storey height at onset of yield.

8.0 EXTERIOR PANELS

Simple details capable of accommodating large drifts result if panels are not located in the plane of the cols (fig 2). The vulnerable corner section may be constructed of metal to limit damage. Floor slabs projecting beyond panels reduce weathering problems mostly to providing compressible fillers between panels and upper channel, at the same time giving support against face loads. The channel must be positioned at a level below that of any transverse beams (fig 4). Storey claddings above that level are fixed to and move with the upper storey. The lower edge of panels are supported either directly by metal angles bolted to the slab panel or on concrete erection corbels or panel ribs (fig 3). Steel wedges are used as temporary supports for vertical adjustment. The space is packed with mortar at a later stage. Face loads are resisted by metal angles and bolts. Reinforced concrete corbels (fig 3) are some times omitted but in this case bolts are subjected to both seismic and gravity load shears, a more severe condition. Protection of the connection against fire too becomes more critical. It is advantageous to give lower storey vertical connection bolts some flexibility should greater deformation than provided for occur. This is the reason for the relatively large space between angles and floor slab (fig 3).

Architectural considerations sometimes require exterior panels to be located between columns in which case the use of details given in Figs 1c and 6 is advantageous as these too allow large storey drifts to be accommodated. Panels are vertically supported at the centre of their bottom edges. In the four corner positions they are laterally held by pins which allow the panels to rotate. The function of the pins is to provide resistance to face loads and also to resist dynamic in-plane shears due to the mass of the panels themselves. From practical erection considerations the metal connections for the pins initially are provided with oversized holes but following erection and adjustment close fitting washers are placed

over the pins and welded in position. Fig 6 also shows how vertical edges of panels are weathered allowing for sliding relative to each other when panels rotate.

Panel separation in an industrial structure may be achieved as shown in figs 7-9.

8.1 WINDOWS AND CURTAIN WALLS

Windows where incorporated into precast panels or part of a curtain wall are dealt with using the principles of Section 8.0 (fig 10). For the case of fairly rigid buildings sufficient flexibility⁽⁵⁾ may be available where window frames are provided with clearances and a suitable bedding material between frame and glass e.g. elastomeric gaskets.

8.2 PARTITIONS

Rigid, strong partitions are undesirable and dangerous in flexible frames (refer to Section 3). For structures subject to moderate deformation the details given in reference⁽¹⁾ may be used. Although there are no weathering problems careful thought must be given to the detailing of all junctions.

8.3 STAIRS

Stairs are as a rule the only available means of egress following an earthquake as lifts usually become non-operational and particular care must be taken to prevent failure and avoid hazards due to brittle heavy enclosures. Rigid stairs tending to act as diagonal struts have been seriously damaged.⁽¹⁾ Separation of stairs can easily be achieved in a number of ways. A common method employed is to fix one end of each flight rigidly to a storey. The landing is split at the centre and either a sliding support is provided below or each flight and half landing is hung flexibly from above (fig 11). Metal plates bridging the gap in the landing are fixed to one side only and free to move in *all* directions relative to the other. Care should be taken that separations are not crossed by rigid conduits for electrical services or fire detectors.

8.4 SUSPENDED CEILINGS

Discussion of their design is beyond the scope of this paper. Requirements are given in reference⁽⁶⁾.

8.5 SPECIFICATION PROVISIONS AND SUPERVISION

Even more so than with other aspects of structural design, success in achieving the desired results in damage control depends on the closest co-operation between all concerned. Architect and builder must have a clear understanding of the structural designer's intention. To achieve this New Zealand MWD include notes with their contract documents explaining separation provisions. An example of this is given in reference⁽¹⁾. Another aspect often overlooked is reduction of separation spaces due to allowed construction tolerances.

8.6 ECONOMICS

In a small country with limited local resources, with industry fully committed by normal building activity and with rescue resources geared to deal with little more than a predictable number of daily traffic accidents, damage in a severe earthquake may result in major disruption of the entire infrastructure of the country. These and other important aspects have been discussed elsewhere⁽⁷⁾. The following comments therefore apply to economics

in a very narrow sense only. Few detailed studies have been made of the economics of damage control measures. The costs in reference⁽⁸⁾ are based on the redesign of individual items but if damage control is to be achieved at minimum cost design for it must start at the planning stage.

In simplistic terms the cost of damage control compared to the alternative option of investing a sum of money equal to the cost of damage control to pay for damage when it occurs might be made as follows: Assume: return period of damaging earthquakes: 25 years. Cost of damage control features: 2% of total building cost. Net return on invested sum (following adjustment for inflation) say: 5%. $0.02 \times \text{building cost} \times 1.02^{25} = 0.07 \times \text{building cost}$. The actual cost of damage as experienced in earthquakes is generally far greater than 7% of the total cost of a building.

8.7 CONCLUSION

Modern structures, particularly ductile frames not incorporating deformation limiting devices are subject to large displacements in earthquakes of moderate and greater intensity. The great potential which exists for non-structural damage is evident both from theory and field observation. Hazards may be created to people in and around a building, its intended structural performance altered and high economic losses result.

Choice of structural form and careful detailing will minimise non-structural damage. To be effective, damage control measures call for close co-operation between architect and engineer at the sketch plan stage of a project and must be clearly understood by all involved, including those responsible for the building's erection.

8.8 ACKNOWLEDGEMENT

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8.9 REFERENCES

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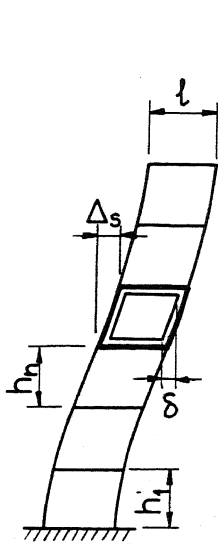


Fig. 1(a)

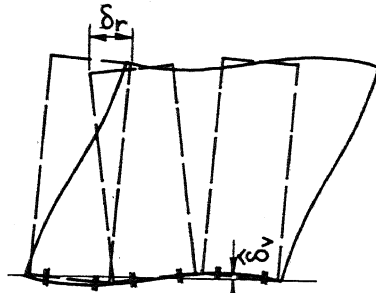


Fig. 1(b)

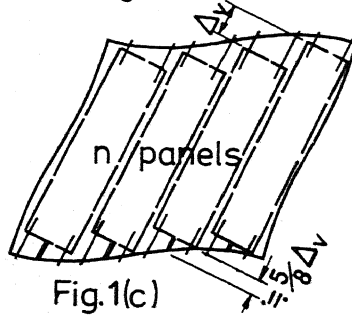


Fig. 1(c)

Example
 6 stories, Class II, Zone A.
 $l = 20'$ $h_1 = 13'$ $h_{2-6} = 11'$
 cols 30"sq., beams 24"x18"

$\frac{1}{3}$ El Centro N-S	type A ₁					
Δ_s	$2.2\Delta_{elast.} = 0.82''$			$2.2\Delta_{elast.} = 0.80''$		
δ	0.66''			0.65''		
n	3	4	6	3	4	6
δ_r	0.22	0.20	0.25	0.22	0.20	0.25
$\hat{\delta}_v$	0.12	0.10	0.08	0.12	0.10	0.08
Δ_v	0.58	0.42	0.30	0.58	0.42	0.30

Fig. 1(d)

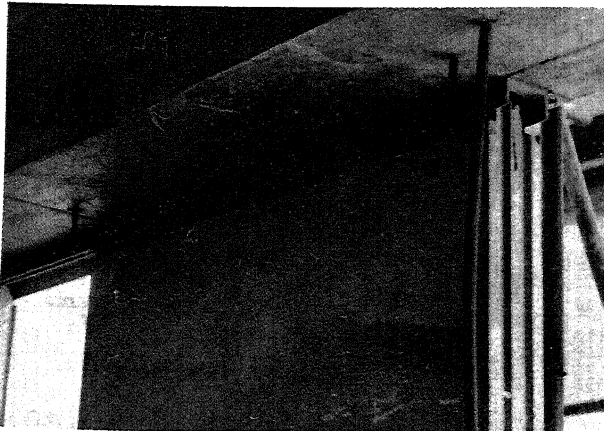


Fig. 2



Fig. 3

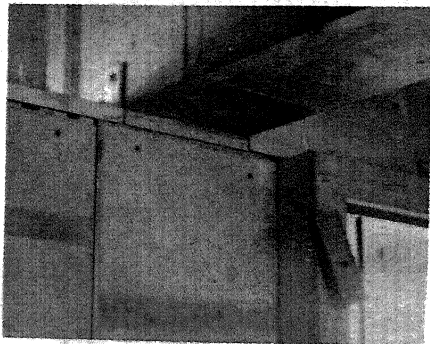


Fig. 4



Fig. 5

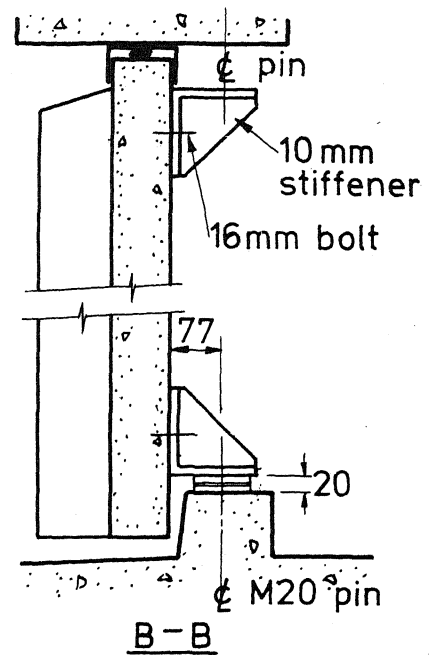
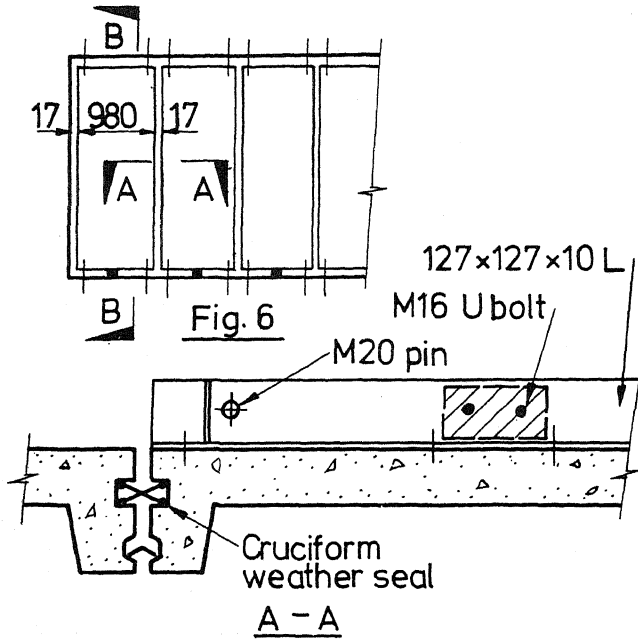


Fig. 7

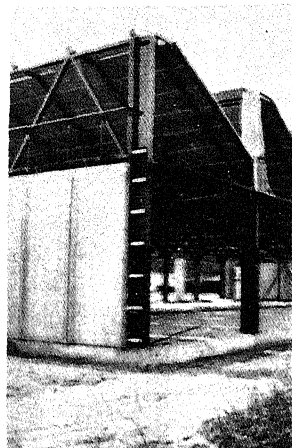


Fig. 8

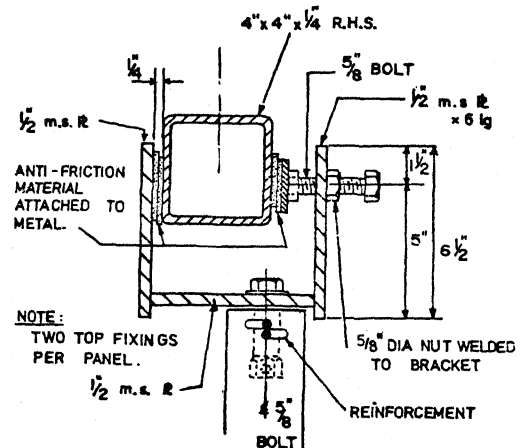


Fig. 9

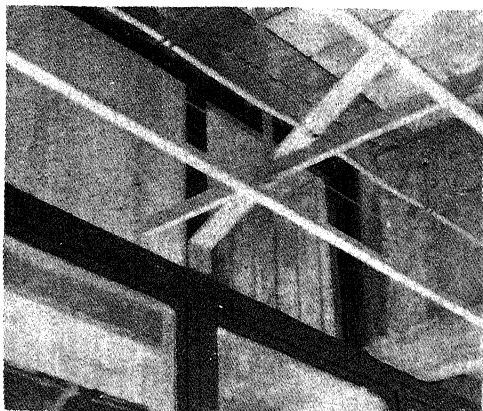


Fig. 10



Fig. 11

DISCUSSION

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The paper gives useful details for separation of non - structural elements and also an ingenious method of avoiding the stiffening effect of staircases by hanging the midlanding from above, through flexible suspenders.

However the paper does not deal with building separations i.e. separation between parts of buildings or buildings on the same site separated from each other. The New Zealand Code (i) stipulates that the coverings of such joints shall be durable and shall allow three dimensional movements. It would be very informative and useful if the author could give typical details of such joints for floors and roofs as adopted in New Zealand practice.

Reference:

1. NZS 4203:1976 New Zealand Standard Code of Practice for General Structural Design and Design Loadings for Buildings Part 3 : Earthquake Provisions.

Author's Closure

Not received.