PRECAST CONCRETE BRACED FRAMES INCORPORATING LOAD-LIMITING ENERGY-DISSIPATING DEVICES IN AN EARTHQUAKE RESISTANT BUILDING

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SUMMARY

A novel earthquake resisting system, used for an irregular six storey office building, is described. The system employs a precast concrete braced frame incorporating load-limiting energy-dissipating devices. The devices, termed "inserts", take the form of enclosed axially yielding short steel members.

A series of inelastic dynamic analyses indicates that the system very successfully combines the inherent strength and stiffness of the cross-braced frame with the reliable ductility of the yielding inserts.

The concept is considered to provide a practical, economic and effective new approach to the problem of resisting seismic loads.

1. INTRODUCTION

It is widely recognised that conventional structures likely to be subject to strong seismic attack cannot feasibly be designed to remain elastic. They must thus possess the ability to sustain significant deformations beyond the elastic limit. This essential requirement for ductility in the yielding elements can be satisfied if post-elastic deformation occurs in a mode which limits the demand to practical levels, and if the yielding elements have sufficient reliable ductility to meet the demand.

A further requirement perhaps not so generally recognised is the desirability, or indeed necessity, to minimise non structural damage.

This paper describes a building structure which satisfies the above requirements by providing strength, ductility, and stiffness in a novel manner. It combines the inherently strong and stiff form of a cross braced reinforced concrete frame with the reliable energy dissipating characteristics of mild steel. The cross braced elements are precast, with the advantage that brings to the construction operations, and they also form part of the architectural envelope. The building, a view of which is shown in fig. 1, is six storey plus a basement with a total area of 4700 m^2 and is currently under construction in Wanganui, New Zealand.

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2. DESCRIPTION OF STRUCTURE

Seismic loads are resisted by the perimeter walls which comprise a series of 5 m long x 3 m high precast concrete panels and reinforced concrete columns. Connections between panels and columns are made of welded steel later encased in concrete.

The very high forces which a large earthquake would produce in the connections and members of the structure are controlled by the introduction of steel devices to the bottom ends of the diagonal members in the lower three storeys. The central component of the device, termed an insert, is formed from a mild steel section which yields axially at a given force level. Details of the panels and inserts are given in section 5.

An important feature of the system is the moment resisting frame action which occurs in conjunction with the primary truss action of the structure. Before yielding of the inserts the frame stiffness constitutes about 15% of the structure stiffness so that it is not very significant at that stage. After yielding of the inserts, however, the frame remains elastic and it then performs two important fuctions. The first is to force inserts at all storeys to yield rather than post elastic deformation being limited to one storey, with the consequent increases in interstorey deflection and insert ductility demand in that storey. Secondly, dynamic analyses have shown that the frame significantly limits post yield deflections and the associated ductility demands in all storeys.

A typical deflected shape of a wall under seismic loading is shown in fig. 2.

3. BUILDING DESIGN AND ANALYSIS

Design of the primary yielding members, the steel inserts, was based on a static space frame analysis using the equivalent static force method of the New Zealand loadings code NZS 4203 (1). Other elements were designed generally to ensure that yielding did not occur at other locations. One aim of the design was to minimise the necessity to detail for control of damage to non-structural elements. Partitions have not been separated from the frame, the design being based on the assumption that they could sustain up to 8 mm racking without damage. The windows are isolated from lateral deformations.

Inelastic time history analyses were done with a range of earthquakes using the DRAIN-2D program (2) to test the sensitivity of the response to the analysis assumptions and to help optimise the strength and stiffness properties of the insert. Further details of the design and both static and dynamic analyses are contained in ref. 3.

4. RESULTS OF DYNAMIC ANALYSES

A summary of results, with the insert properties as finally designed, is presented in table 1. For all realistic models (ie excluding analysis 9), the required insert ductilities are lower than the level demonstrated to be available by the tests described in section 6, and the desirable limit on interstorey drifts is exceeded only for the Parkfield record, which is not considered to be a credible event in Wanganui. Analysis 9 used an artificially low frame stiffness and gave increases in both ductility demand and drift. This demonstrates the significance of the frame action in controlling the response.

5. PANEL AND INSERT DETAILS

Details of the precast reinforced concrete panels are shown in fig. 3. Separate mild steel plates are cast into the panels and into the columns and are butt welded together to transfer the diagonal axial forces and the secondary frame action forces. Inertia forces are introduced to the panels by connection of the floor slab diaphragms to the panel top chords.

The inserts (fig. 4) are formed from short mild steel thick walled hollow sections which are turned down to a reduced wall thickness over the required yielding length (700 mm). Using this method it is possible to closely control the yield force of the insert by varying the area of steel to suit the measured yield strength of the material supplied. Connection to the panel is made in the original thicker portion of the tube where stresses are below yield. The insert is separated from the surrounding concrete with a steel sleeve giving about 2mm clearance, which is small enough for the concrete to restrain the insert if it distorts laterally under inelastic strains. The inserts are galvanised after fabrication.

6. TESTS ON INSERTS

Axial load tests of several tension/compression load cycles up to ductility factor 6 were performed on two prototype inserts. The test assemblies incorporated a sleeve over the insert to model the lateral support provided by the concrete in the panel. The resulting hysteresis curves are shown in fig. 5 and they indicate very good behaviour with no deterioration in strength.

7. BUILDING COSTS

It has not been possible to separate the costs of the structural system itself from certain architectural features of this particular building. However, the system is considered to be economically competitive: it utilises repetitive precasting and the efficient structural form of the cross braced frame.

8. CONCLUSION

The building described here incorporates a practical and economic structural concept which should ensure that the building can survive a severe earthquake with very little structural or non-structural damage. It is considered that the concept represents a useful new approach to the problem of resisting seismic loads.

ACKNOWLEDGEMENTS

The building described in this paper was designed in the Wanganui District Office of the New Zealand Ministry of Works and Development.

The authors wish to acknowledge a good working relationship with the job architect Mr A.D. Baker, and helpful attitude of the MWD Chief Structural Engineer Mr O.A. Glogau. Mr B.W. Buchanan, Senior Design Engineer, provided useful comments.

The insert tests were carried out in the Central Laboratories of the MWD under the direction of Dr S. Thurston, Structures Engineer.

REFERENCES

1. NZS4203:1976 N.Z Standard Code of Practice for General Structural Design and Design Loadings for Buildings.

2. A.E. Kanaan and G.H. Powell, "DRAIN-2D, a General Purpose Computer Program for Dynamic Analysis of Inelastic Plane Structures" Earthquake Engineering Research Centre, University of California, Berkeley, 1973.

3. C.D. Matthewson and R.A. Davey, "Design of an Earthquake Resistant Building Using Precast Concrete Cross-braced panels and Incorporating Energy Absorbing Devices", Bulletin of the N.Z. National Society for Earthquake Engineering, Vol.12, No. 4, December 1979.

Analysis No	Damping (% critical)	Relative Frame Stiffness (Uncracked = 1.0)	Earthquake Record	Max. Top Displacement (mm)	Max. Interstorey Drift (mm)	Steel Insert Ductility Demand $\frac{(eu)}{(ey)}$
1	5%	1.0	El Centro	16	5.6	3.5
2	5%	1.0	1.5 El Centro	19	7.2	5.0
3	5%	1.0	Al	20	7.1	4.9
4	5%	1.0	Bl	20	8.1	5.7
5	5%	1.0	Parkfield	34	13.4	10.2
6	2½%	1.0	El Centro	21	7.6	5.3
7	5%	0.5	El Centro	19	6.8	4.6
8	5%	0.5	Al	22	8.3	5.8
9	5%	0.1	El Centro	28	16	12

TABLE 1 ANALYSIS RESULTS

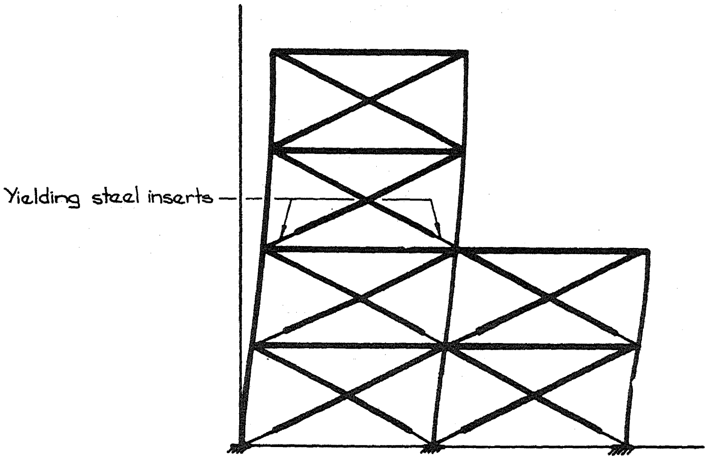


FIGURE 2 Typical Deflected Shape of a Wall Under Seismic Load

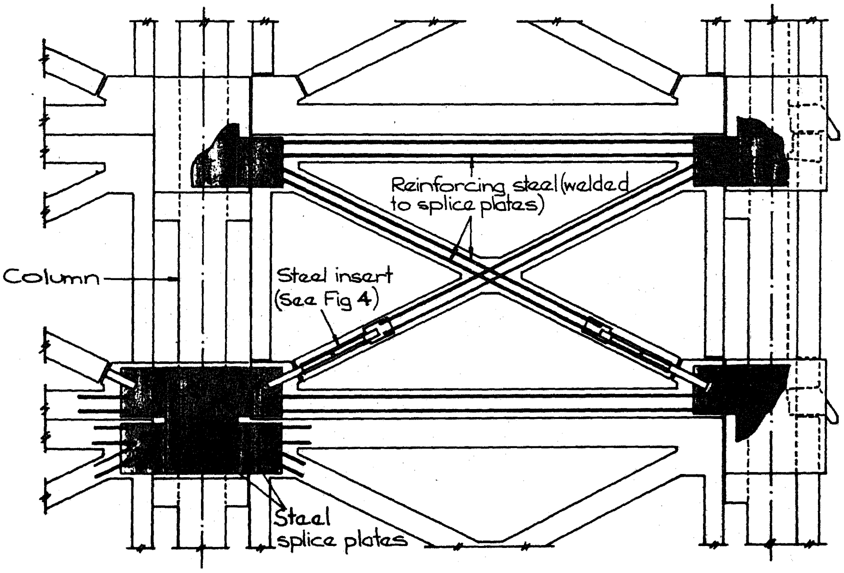


FIGURE 3 Panel Details

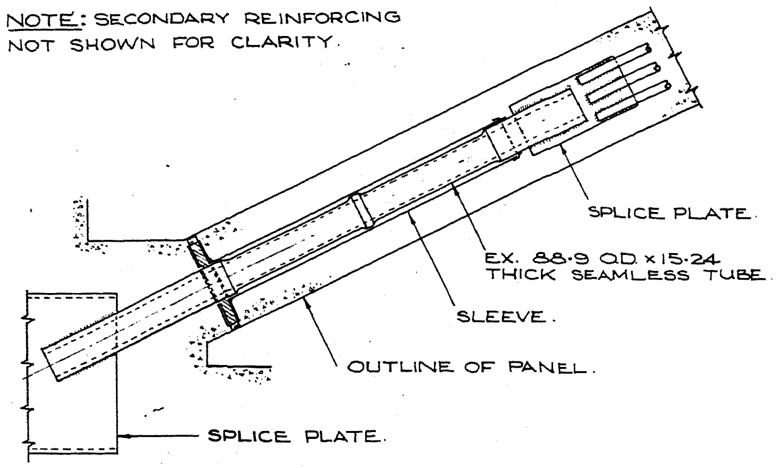
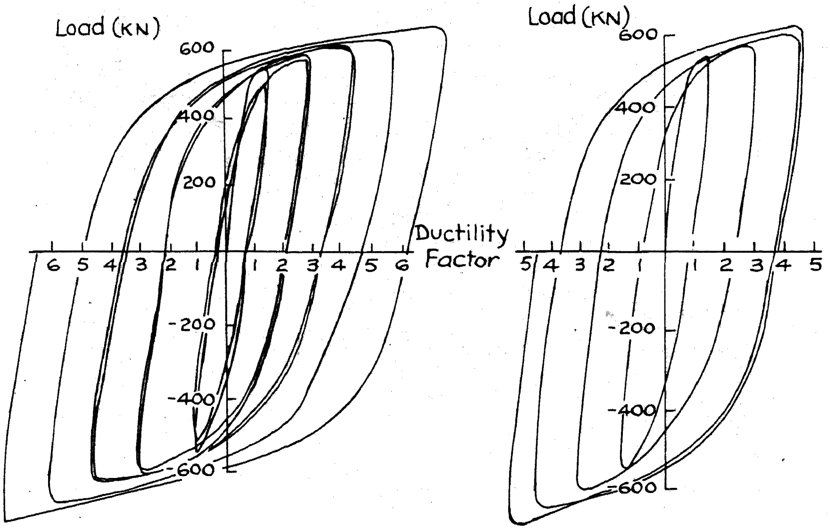


FIGURE 4 Insert Details



Sample 1

Sample 2

FIGURE 5 Hysteresis Curves from Insert Tests