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Tests of Cantilever Action in Damaged Large Panel Structures

Essais sur l'action en porte-à-faux de structures endommagées, composées de grands panneaux

Untersuchung des Kragverhaltens in beschädigten Konstruktionen der Grossplattenbauweise

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1. HIGHLIGHTS

This report describes initial tests being conducted in a major investigation to develop criteria for design and construction of large panel concrete structures. The tests were carried out to determine the stability of large-panel structures in the event of partial loss of support caused by the ineffectiveness of a lower panel. Details of the test structures are intended to permit panels above the one removed, to act as cantilevers from the adjacent undamaged structure.

The tests were carried out to determine if the cantilever portion acted as a single unit, as individual story-high cantilevers or as some intermediate structure. In addition, data needed to design a comprehensive test series were obtained.

A 3/8-scale model representing an end wall of a 6-story large panel building was assembled using details common to North American construction. To represent the ineffective support, one-half of the first story end wall was omitted. As load was applied at each floor level, stresses in the connecting tension ties at each floor level were measured. Tests were conducted for cantilevers of 2 stories, 3 stories, 4 stories and 5 stories. Finally, the 5-story cantilever was loaded to destruction.

Partial movement of joints between panels and floor elements prevented the cantilever from acting as a single unit and complicated the structural behavior. Measured story load versus deflection relationships indicate that performance of the 5-story cantilever was similar to that calculated for a 2-story cantilever.

Measured stresses in the tension ties at each floor level were consistently less than the calculated values.

2. TEST STRUCTURE

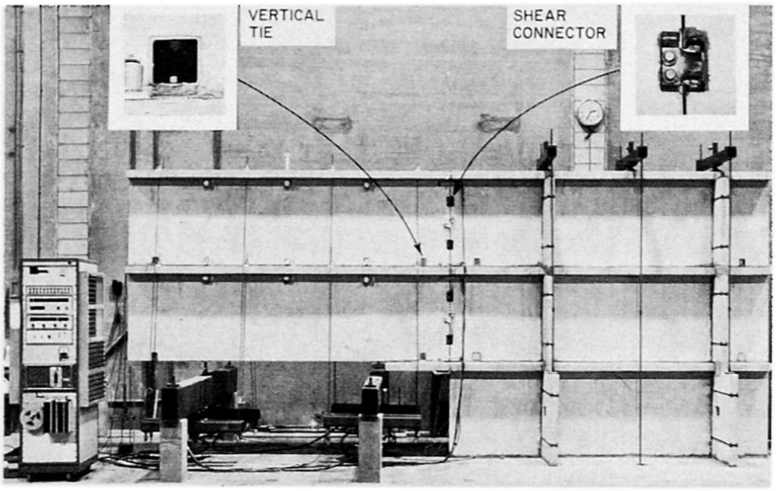

Fig. 1 - Two Story Cantilever

Construction and testing started with a 2-story cantilever as shown in Fig. 1.

Wall panels were 3-in. (76 mm) thick, 36-in. (914 mm) high and 11-ft. 3-in. (3.4 m) long. Two shear connectors were used at the vertical joint between panels at each story. Hollow core slabs spanning between wall panels were represented in the test structure by short stub sections. The floor stub elements were 3-in. (76 mm) thick to represent 8-in. (203 mm) thick slabs in the prototype structure. Spaces between the ends of the slabs were provided by a 1-in. (25 mm) wide slot through the length of the element.

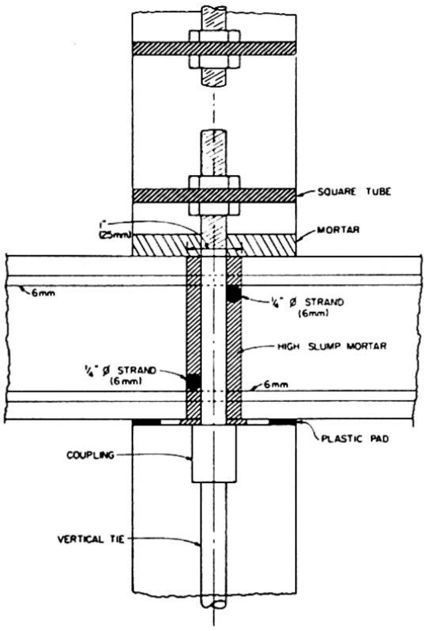

Fig. 2 - Joint Details

In Fig. 2, a detail of the joint at a vertical tie shows the horizontal tie consisting of 1/4-in. (6.4 mm) strand. This tie was placed in the slot between ends of the floor stubs and was continuous the length of the specimen. A fluid mortar was placed in the joint shown in Fig. 2.

After the floor slab stubs were placed, a wall panel was positioned over the joint. Dry mortar was then packed between the floor element and the wall panel above. Continuous vertical ties located 11 1/4-in. (285 mm) from each end of each wall panel were used to tie the newly placed panel to the structure.

Deflections, applied loads, strains in the ties, and joint movements were measured.(1) Strain gaged load cells were used to sense applied loads. A linear potentiometer was used to measure cantilever deflection. Strains in ties were sensed with bonded electrical resistance strain gages. Dial gages were used to sense horizontal and vertical joint slip. Vertical joint opening was monitored with potentiometers.

3. TEST PROGRAM

The cantilever structure was tested using hydraulic jacks to apply force through loading rods to 8 points on each floor. The load was applied in increments to a maximum representing full dead load and one-third of design live load. This combination was selected as representative of ordinary residential loading.(2,3)

At completion of the test on the 2-story cantilever, the free end was jacked back to its original position. A new story was added to the top of the test specimen to form a 3-story cantilever. The test load was then applied to the new structure. This process was repeated until a 5-story cantilever had been constructed and tested.

After dead load plus one-third of design live load had been applied, the complete 5-story cantilever structure was loaded to destruction. As load was increased, the vertical ties connecting the bottom panel to the structure fractured, as shown in Fig. 3. Continued loading produced additional tie fractures until only the top panel remained. Further application of load resulted in slip between the panel and the floor above.

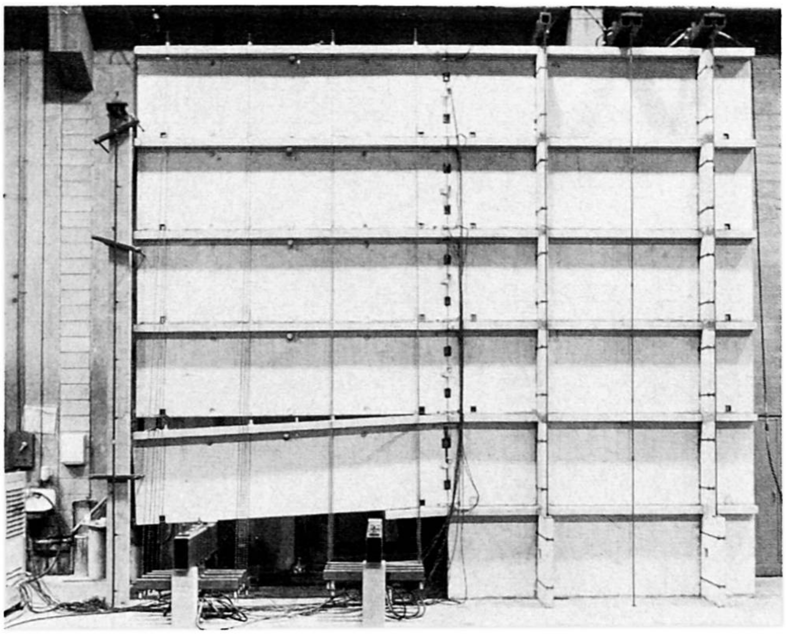

Fig. 3 - Test Structure After Fracture of Vertical Tie at Floor Level 2

4. TEST RESULTS

Measured story load versus deflection relationships for each service load test are shown in Fig. 4. The test load of 8.2 kips (36.4 kN) per story is marked on the load axis.

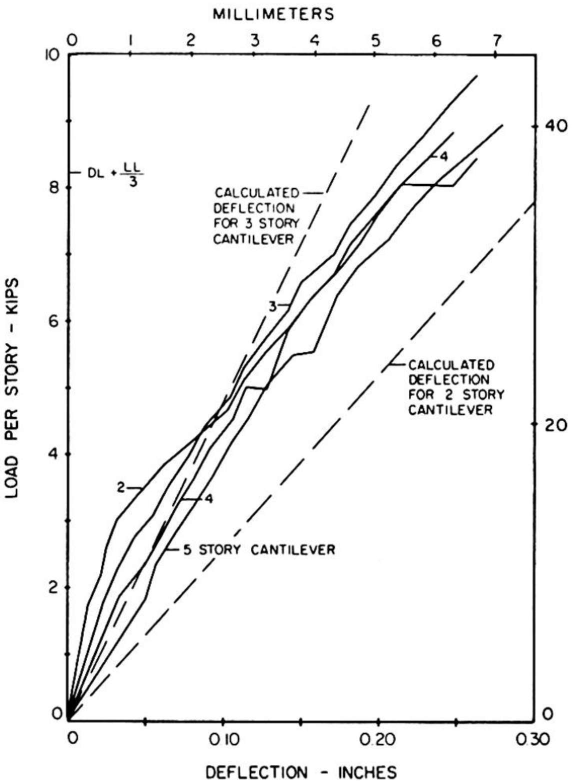

Fig. 4 - Measured Deflections at Low Loads

Measured deflections of the 5-story cantilever as it was loaded to destruction are shown in Fig. 5. Comparison of measured

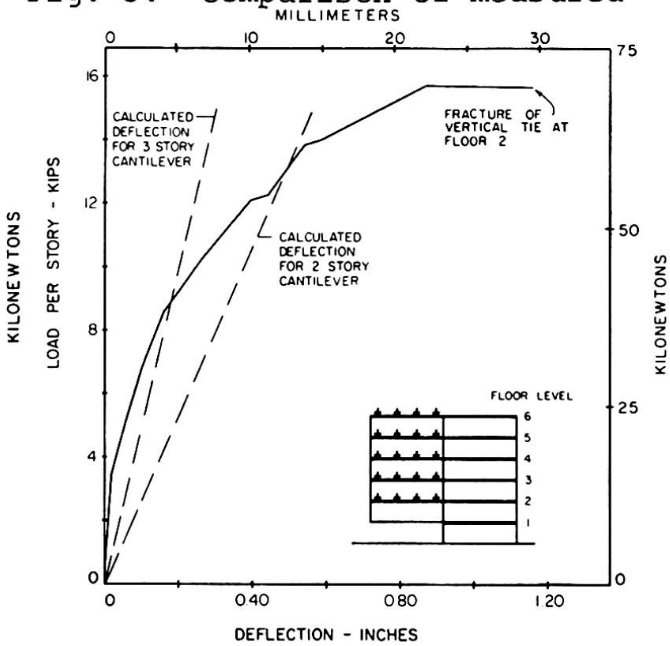

Fig. 5 - Deflection Measured During Test to Destruction

deflections with those calculated suggests that the upper two stories did not act compositely at higher loads.

Measured load versus strand stress in the 2-story cantilever is shown in Fig. 6. Figure 7 shows load versus strand stress for the test to destruction. In all cases the observed strand stress was substantially lower than values calculated assuming a cracked composite section. For example, the calculated maximum stress on the 3-story cantilever at a load of 8.2 kips (36.4 kN) per story was 105 ksi (724 MPa). Stress obtained from measured strain was about 55 ksi (380 MPa).

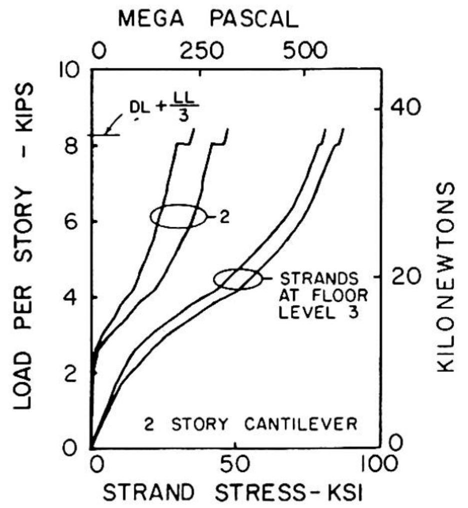

Fig. 6 - Measured Strand Stress

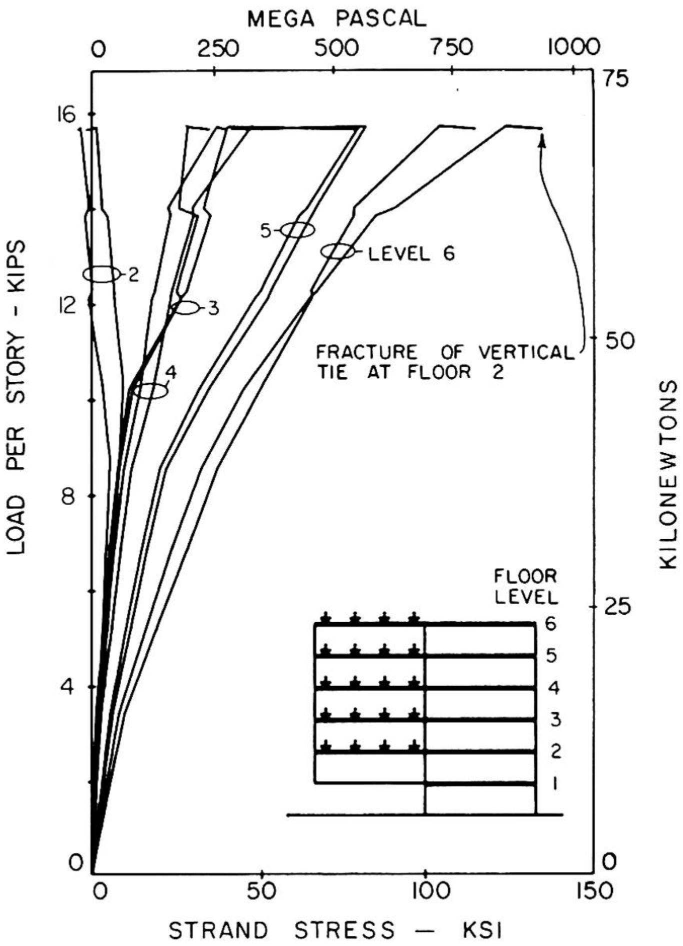

Fig. 7 - Strand Stress During Test to Destruction

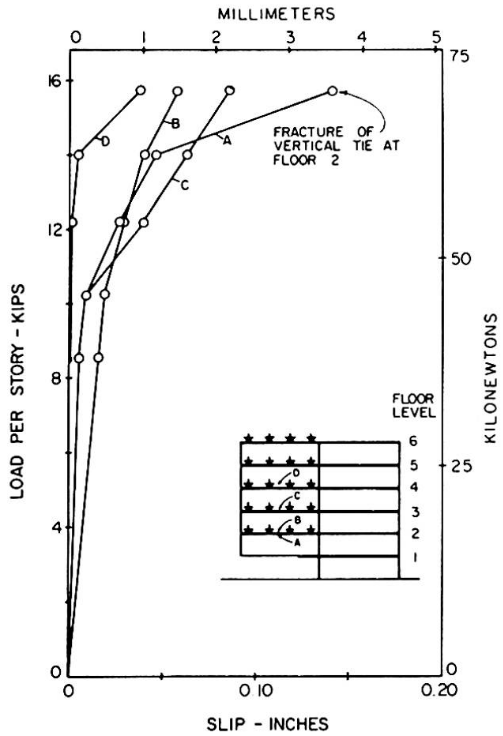

Fig. 8 - Slip During Test to Destruction

The differences between measured and calculated deflections and stress are attributed to slip at the horizontal joints in the lower stories. Slip measured during the test to destruction is shown in Fig. 8.

5. CONCLUSIONS

These tests indicate that large panel structures as built in North America can be constructed so that progressive collapse is avoided even when large portions of lower story supports become ineffective. Further testing and analysis will be directed toward determining minimum tie requirements to ensure self-support of the wall panels in the event of catastrophic loss of a lower panel.

6. ACKNOWLEDGMENT

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7. REFERENCES

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SUMMARY

This report describes a part of a major study to develop design criteria to minimize the possibility of progressive collapse. Large panel precast concrete structures as built in North America were considered. A 3/8-scale structure representing an end wall of a 6-story building was constructed and tested. The tests were used to determine the stability of large panel structures in the event of partial loss of support by accidental removal of a lower panel. Results of these tests indicate that if suitable details are provided, progressive collapse can be avoided even when large portions of lower stories become ineffective.

RESUME

Une étude majeure a été entreprise afin de développer des règles de dimensionnement pour minimiser la possibilité d'effondrement de proche en proche, dans le cas de grands panneaux préfabriqués pour structures en béton construites en Amérique du Nord. Une structure à l'échelle 3:8, représentant la paroi extrême d'un bâtiment de six étages fut construite et soumise à l'épreuve. Les essais devaient déterminer la stabilité de la structure composée de grands panneaux en cas de perte partielle d'appui, par suite du déplacement accidentel d'un panneau inférieur. Les résultats de ces essais ont montré que des détails constructifs bien conçus peuvent éviter l'effondrement de proche en proche, même lorsqu'une partie importante des étages inférieurs disparait.

ZUSAMMENFASSUNG

Um den fortschreitenden Einsturz der in Nordamerika aus grossen Betonfertigteil-Platten hergestellten mehrstöckigen Bauten auszuschliessen, wird zur Zeit eine grosse Untersuchung durchgeführt mit dem Ziel, entsprechende Bemessungsregeln zu entwickeln. Im Rahmen der Untersuchung wurde ein Modell der äusseren Wand eines 6-stöckigen Gebäudes im Massstab 3/8 hergestellt und unter der Belastung geprüft. Die Versuche dienten zur Bestimmung der Stabilität solcher Bauten unter der Voraussetzung, dass die untere Platte zufälligerweise ausfällt. Die Versuchsergebnisse haben gezeigt, dass bei Anordnung geeigneter Massnahmen ein fortschreitender Zusammenbruch vermeidbar ist, selbst wenn grosse Teile der unteren Stockwerke nicht mehr wirksam sind.