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PROPOSED TEST AND EVALUATION PROCEDURE FOR EXTERNAL CURTAIN WALL GLAZING SYSTEMS TO SIMULATE SEISMIC LOADING

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REFERENCE

Thurston, S.J. and King, A.B. 1993. Proposed Test and Evaluation Procedure for External Curtain Wall Glazing Systems to Simulate Seismic Loading. Building Research Association of New Zealand, Technical Recommendation 15. Judgeford, New Zealand.

DESCRIPTION

This Technical Recommendation specifies a laboratory test procedure to enable the seismic performance of external glazing systems to be assessed. It also specifies an evaluation method that uses the test results to provide the seismic defomations that can be safely sustained by the glazing wall system, if properly installed in a building. The relationship between computed inter-storey deflections, as calculated during design, and that required during testing of the glass curtain walls, is discussed. It is recognised that many of the glazing failures that have occurred in historic earthquakes may have been the result of poor installation procedures, inadequate attention to detail and the common use of semi-rigid putty and bedding compounds which restrict glass edge movement.

RELEVANCE

How curtain wall glazing systems respond when buildings are subject to seismic loading is not fully understood and may represent a hazard for nearby pedestrians and occupants of the building. A suitable test and evaluation procedure for determining earthquake performance of such systems is required. The test method can be used to determine behaviour of traditional, modem or innovative glazing systems, and to demonstrate that they can achieve the performance criteria set out by the New Zealand Building Code.

The test method in this Technical Recommendation seeks to evaluate the performance of glazing systems and their associated components when subjected to simulated in-plane racking movements. In particular, the maximum test inter-storey displacement (in-plane) that a particular glazing system can achieve before failure (as defined below), can be determined.

SANZ (1992) requires that secondary elements be capable of accommodating building inter-storey deflections, determined from the calculated code loading deflections factored by the building ductility deform under seismic loadings. Appropriate criteria would be that curtain wall glazing (a) sustains no damage during moderate earthquakes and (b) does not fall from the building in a manner that threatens life under severe earthquakes.

SCOPE AND ACCEPTANCE

This Technical Recommendation details how to assess performance of external glazing systems when they are installed on buildings subject to earthquakes. It is essential that laboratory specimens be precisely the same as installed in the field, including all weather proofing details, as small differences can significantly influence behaviour. The window size may be reduced for testing purposes but it must be at least half size and the aspect ratio cannot be reduced. Only an in-plane test configuration is required, although an adjustment in some end details and the application of non-planar skewness is recommended. Testing (Thurston and King, 1992) has indicated that inclusion of out-of-plane loading on the in-plane loading does not result in a significantly more critical loading case. For glazing systems where this is unlikely to be correct, this recommendation is not applicable.

It is recommended that glazing systems tested and evaluated in accordance with this Technical Recommendation be accepted as achieving under seismic loads the factored inter-storey displacement tested in the laboratory.

SPECIFICATION

Specimen and Construction

A single full-sized specimen of either a double storey (configuration "d", Figure 1) or a single storey plus two half storeys (configuration "s", Figure 2) shall be supplied by the manufacturer for testing. Glazing systems which incorporate a primary structural system which is supported only within each floor level, and which includes some mechanism within the plane of the glazing system that permits discontinuity, shall be tested using configuration "d". Systems where the floor level occurs part way up a glazing panel shall also be tested in configuration "d". Systems which have the glazing supporting members (such as the mullion framing members) continuous between adjacent floors, should be tested using configuration "s". The two half-storey panels of configuration "s" should not rotate within the plane of the glazing system. Where applicable, glazing systems incorporating "vision" and "opaque" panels shall also be modelled in the specimen. The eccentricity and connections between test load beam and glazing panel shall be similar to that used in actual construction.

Specifications of components and type of glazing system shall be provided by the manufacturer and shall include (although not be limited to) the following:

(a) description of the glazing system and the anticipated mode of accommodating the in-plane deformation;

(b) type and properties of framing members (mullions/transoms) if applicable;

(c) details of fixing of the members to the equivalent floor level of a building;

(d) type, thickness, setting details, entrapment, and clearance of the glass (to framing members where applicable;

(e) type and properties of gasket/silicone sealant (including bead dimensions).

The erection of the glazing specimen shall be carried out in accordance with manufacturer's specifications. The specimens shall, as far as possible, be representative of the minimum construction levels specified by the manufacturer with respect to dimensions, material and fixings. An average standard of workmanship is to be used. Where practicable, specimens shall be assembled and tested in conditions representative of the actual condition, e.g. if the glazing system is to be factory assembled and transported to site, then this method of fabrication shall be followed. The number and type of fixings between the glazing system framing members and the building shall be specified by the manufacturer, and form an integral part of the test specimen.

The components to be included in the test shall be the same as used in a finished glazing system of a real building. Architectural coverings such as transom or mullion covers shall be included.

Drift Limits

The racking test may either target a predetermined drift limit, or test a glazing system to destruction, to determine the upper bound of the drift limit that can be tolerated. In the former, the test drift limit shall be determined by multiplying the calculated inelastic inter-storey seismic drift for the ultimate limit state by the factor FDRIFT. In the latter, the drift limit that can be tolerated by a particular glazing system shall be determined by dividing the achieved test drift limit by FDRIFT. The factor FDRIFT accounts for analytical uncertainties (ie. concrete beam inelastic "growth" during a large seismic event), and shall be taken as 1.0 for structures where the primary seismic resisting elements are designed to have a structural ductility factor (μ) less than or equal to 3. FDRIFT shall equal 1.3 for a structural ductility factor of 6. Linear interpolation shall be used for intermediate ductility factors. Should the drift limits be governed by wind rather than seismic loading, FDRIFT is 1.0.

The calculated seismic drift limit shall either be derived from inelastic analysis or from elastic (modal or static) analysis factored by the ductility factor, as detailed in DZ 4203 (SANZ, 1992) using material properties as detailed in the appropriate materials codes. Values in frame buildings computed by static or modal analysis should be increased by 30% to allow for variations in the post-elastic building deflected shape. Torsion and P-delta effects should be conservatively estimated if not included directly in the analysis. Stiffening effects of non-structural elements may be ignored. The serviceability seismic drift limits can be taken as one sixth of the ultimate limits (SANZ, 1992).

Test Rig

The test rig shall have the ability to have either "free sliding" or "locked" horizontal beams, which are sufficiently rigid to support the specimen without distortion, both at rest (under self-weight) and during racking. The beams simulate the floor levels of buildings and shall be attached to columns which are rigidly restrained from movement in any direction. The load shall be applied at an angle (skew) of 1% to the plane of the glass curtain wall. This provides some out-of-plane loading and twist on the wall. In particular this is to ensure that if a grooved sliding portion of the frame comes off a guide or runner, then the frame will move sideways, preventing realignment of the groove and runner on the return stroke. Skewness can be introduced by installing packing plates in the sliding connection between the load beam and supporting column of the load rig.

For unitised systems two additional features are required:

(a) Include appropriate allowances for secondary element clearances. In particular, at locations simulating building corners or connection to a concrete shear wall in the same plane, the interlocking transoms of unitised systems shall be partially restrained from slipping relative to each other using a system of equal or greater strength and stiffness than will be used in actual buildings. As this slip may be a major deformation mechanism that will occur in practice, completely locking the slip may be unduly conservative.

(b) Slip surfaces shall be extended to ensure that unrealistic misalignment at the extremities of the test specimen is prevented. For instance, at the ends of the test curtain walls simulating the situation where the glass wall continues indefinitely, a common situation is where one grooved mullion can slide along, and eventually off, a runner of the transom below. A slight lateral shift then prevents re-alignment on the return stroke, and the transoms are prevented from sliding back to their initial positions. This is shown in Figure 3. Although this may occur at a corner or discontinuity in a glass curtain wall, it will not occur in a continuous wall, as the adjacent panel provides a continuation of the runner preventing the grooved section of mullion from shifting laterally. Thus an extension of the runner is required as shown in Figure 4.

The test rig shall be able to accept a double storey (configuration "d") or a single storey plus two half storeys configuration (configuration "s").

The rig shall also be able to impose zero inter-storey drift of the adjacent storey to the specimen during racking as shown in Figure 1. This shape conservatively models the curvature of a building as it deforms under earthquake excitation. To achieve the required deformations in configuration "s", the two bottom horizontal members shall be permitted to slide. They should be braced to ensure both members move in unison.

Specimen Dimensions

Most buildings have inter-storey heights ranging from 2.4 to 4.0 m. Ideally, the test rig should be able to test details and storey height for a particular real building. To avoid altering a test rig for each storey height, an inter-storey height of H may be used in the test and the results extrapolated for other inter-storey heights, if the following limitations are satisfied: (a) the actual storey height can be no more than 50% more or 20% less than H; (b) the actual glass aspect ratio (height/width) shall be no more than 30% more or 5% less than that tested. The allowable displacement limits for other inter-storey heights shall be determined by multiplying the test displacement with the factor of actual height divided by H.

The minimum width of the specimens shall be 1.5 x H and a minimum of three panels shall be tested.

Displacement Rate and Displacement Pattern

A displacement frequency of F hertz shall be applied for inter-storey displacements of D mm, where F equals 40/D hertz.

The test shall be carried out using a double amplitude cyclic procedure incrementing the displacement in selected increments to the test inter-storey displacement, or to failure. A saw-tooth or sinusoidal displacement function, with five cycles being conducted at each amplitude, shall be used throughout.

TEST PROCEDURE

The test procedure is designed to determine performance of the curtain wall at serviceability deflections and the maximum inter-storey deflection that the wall can be cycled to without failure. The testing organisation shall also determine the source of major deformations in the wall system whereby the wall achieves the imposed inter-storey deflections. The methods to achieve this shall include:

(a) marking potential slip surfaces, e.g. use felt pen or similar to draw a straight line across the glass to frame junction at the middle of each glass pane side, mark interlocking transoms and mullions for relative slip, etc.

(b) at suitable stages of testing, statically push the wall to deflection X, measure slips at marked locations and photograph zones of noted deformation. Then pull the wall to deflection -X, photograph and measure as above. The value X shall be taken (as a minimum) as the serviceability deflection and as a deflection of at least 0.5 x TD, where TD is the target test deflection.

(c) from the photographs, measurement as in (b) above, comparisons of load beam and glass-line deflections, and other observations, to determine the source of major deformations.

Using the appropriate deflected shape regime as shown in Figure 1, carry out the following procedure.

(a) Calculate a target test inter-storey displacement (TD) from the calculated drift limit as defined above.

Example: A concrete building of ductility factor = 4 (ie., FDRIFT - 1.10) with a 3.4 m inter-storey height is calculated as having a code (SANZ, 1992) force level inter-storey deflection of 11.4 mm, using a static elastic analysis (i.e., factor of 1.3 required as above). A 15% allowance is also made for torsion and P-delta effects are considered to be negligible. The estimated building maximum probable earthquake inter-storey deflection is thus 1.1 x 11.4 x 4 x 1.3 x 1.15 = 75 mm. If the test inter-storey height = 2.8 m then the maximum required test displacement = 75 x (2.8/3.4) = 62 mm.

(b) Install the glazing system in the test rig. Condition the specimen for a minimum of 15 days if silicone sealant is used in the assembly.

(c) Cyclically displace the glazing system to the serviceability inter-storey deflection (measured at the glass line) for 20 cycles at a frequency of F hertz defined above using a sinusoidal displacement pattern. Record any damage to the glazing wall and repair if desired. Any reduction of the capacity of the system to provide a water seal should not noted.

(d) Optionally apply 5 cycles at F hertz to the glazing system at deflections less than TD. Record damage. It is required that deflections be measured at the glass line for calculations of inter-storey deflections. Where this exceeds the capability of the deflection gauges, the deflection of the actuator may be proportioned as long as the relationship between actuator deflection and glass deflection is determined at an imposed deflection of at least 60 mm.

(e) Apply five cycles at F hertz to the glazing system at deflection TD. Record damage.

TEST INSTRUMENTATION AND DATA RECORDING

Measure peak displacement (both directions) at all sliding beam members and at the glass line at all "floor" locations. Measure peak applied loads. Measure and photograph slips as described in the previous section at peak static deformations.

Record the behaviour of the system throughout the test. Note the displacements and cycles when either glass, gaskets, frame or other elements are dislodged from their installed position or show signs of distress.

Gaskets may be reinstalled on completion of the given cycle groups. Details and photographs of glass failure (location, general shape, stage in testing) shall be provided. In addition, the recording and reduction of data shall include the following:

(a) Description and specification of glazing system;

(b) Load-deflection plots as measured at the glass line up to an inter-storey displacement of 60 mm. For greater displacements the load versus actuator displacement plot will suffice;

(c) Plots relating actuator deflection to the deflection recorded at other gauges;

(d) Summary of measured slips and a description of the system deformation mechanism.

EVALUATION

During an earthquake the main hazard identified with curtain wall glazing is falling glass or glazing components. The safety of occupants trying to get out of buildings and the safety of pedestrians in the vicinity of buildings is the main concern.

The glazing system shall be deemed to have satisfied a "test inter-storey displacement" only when no failure occurred after five cycles to this displacement, applied as above. Failure shall be deemed to have occurred when either glass fallout of shards of glass more than 50 mm long or total glass fallout of greater than 200 cm^2 (in small portions) or potentially dangerous framing elements (e.g. weight more than 0.5 kg or "spear-like") have fallen. This material includes the weight of any glass, architectural cover, fixings, bolts, etc. The glazing system shall be deemed to have achieved the test displacement when no failure occurs.

Where failure (as defined above) occurred before the required test displacement was imposed, the glazing system shall be deemed to have achieved 1/FDRIFT multiplied by the maximum inter-storey displacement achieved without failure.

BASIS

Studies were undertaken by BRANZ (Wright, 1989) to consider the types of in-plane deformation that can be imposed on a glazing system and to determine the significance of these deformations on the overall performance of glazing systems. The studies concluded that the main deformation affecting exterior curtain wall glazing systems is in-plane racking. A test programme and test rig were developed to evaluate the seismic resistance of full size specimens simulating inter-storey deflections and building curvatures.

Using the recommended test rig, full-sized in-plane racking tests on five different generic exterior glazing systems were carried out at BRANZ (Lim and King 1991; King and Thurston 1992). This was extended to three generic glazing systems which included an exterior corner (Thurston and King, 1992). It was concluded that the ability of full-size curtain wall glazing systems to withstand major racking actions could be modelled within a laboratory environment using an in-plane loading system applied to a planar structure.

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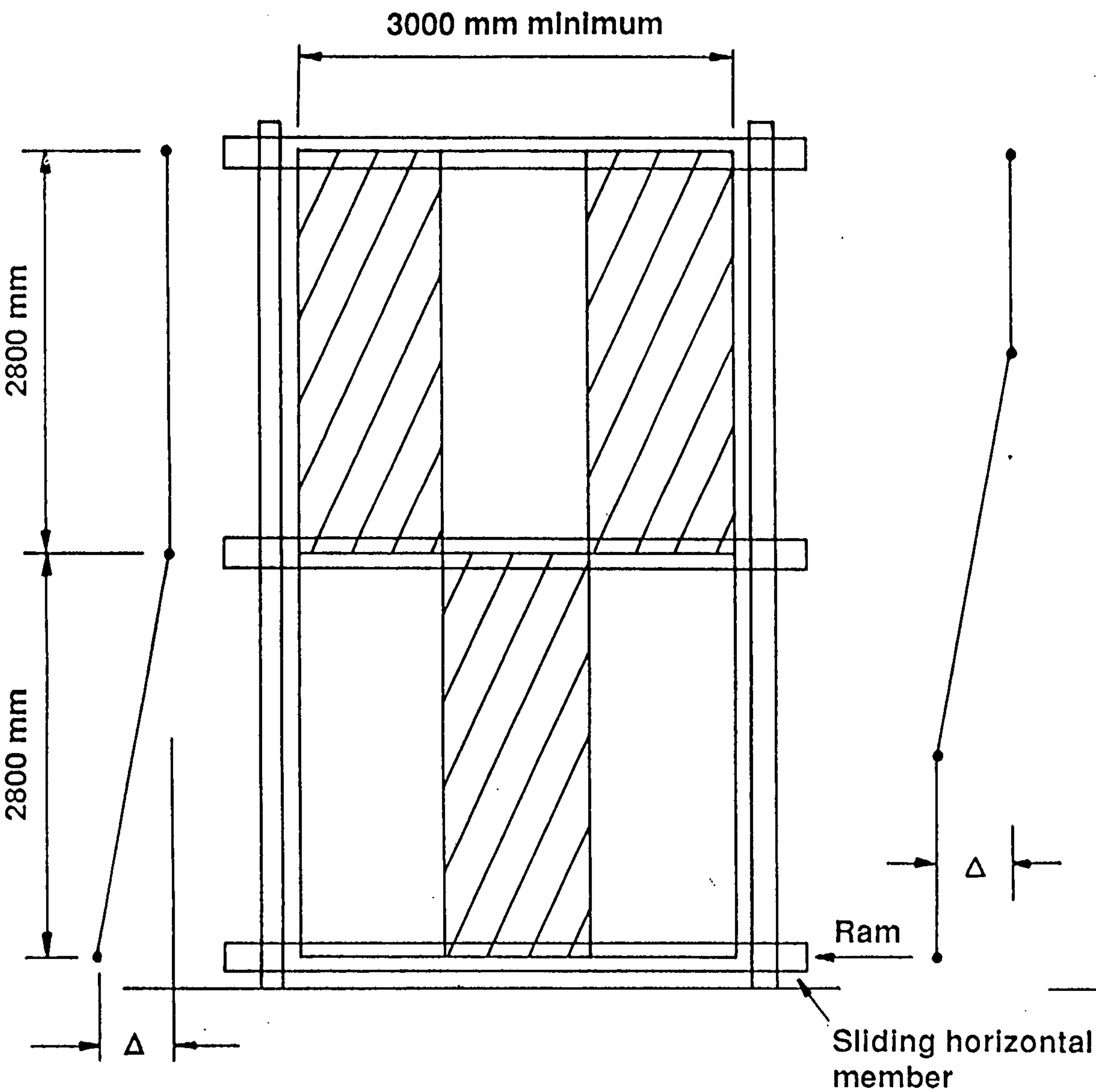

Figure 1 Double storey configuration (configuration "d")

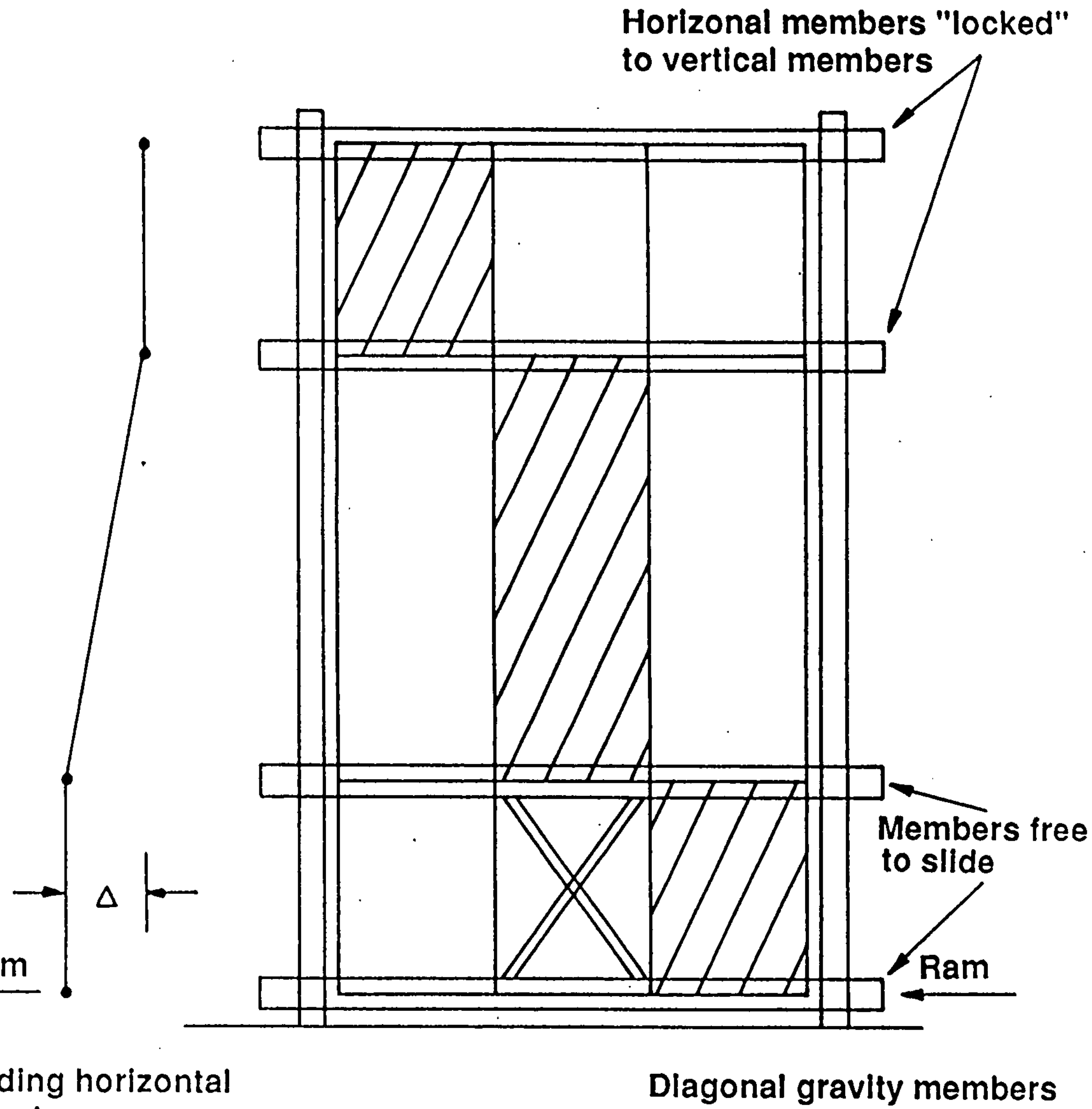

Figure 2 Single storey plus two half storeys configuration (configuration "s")

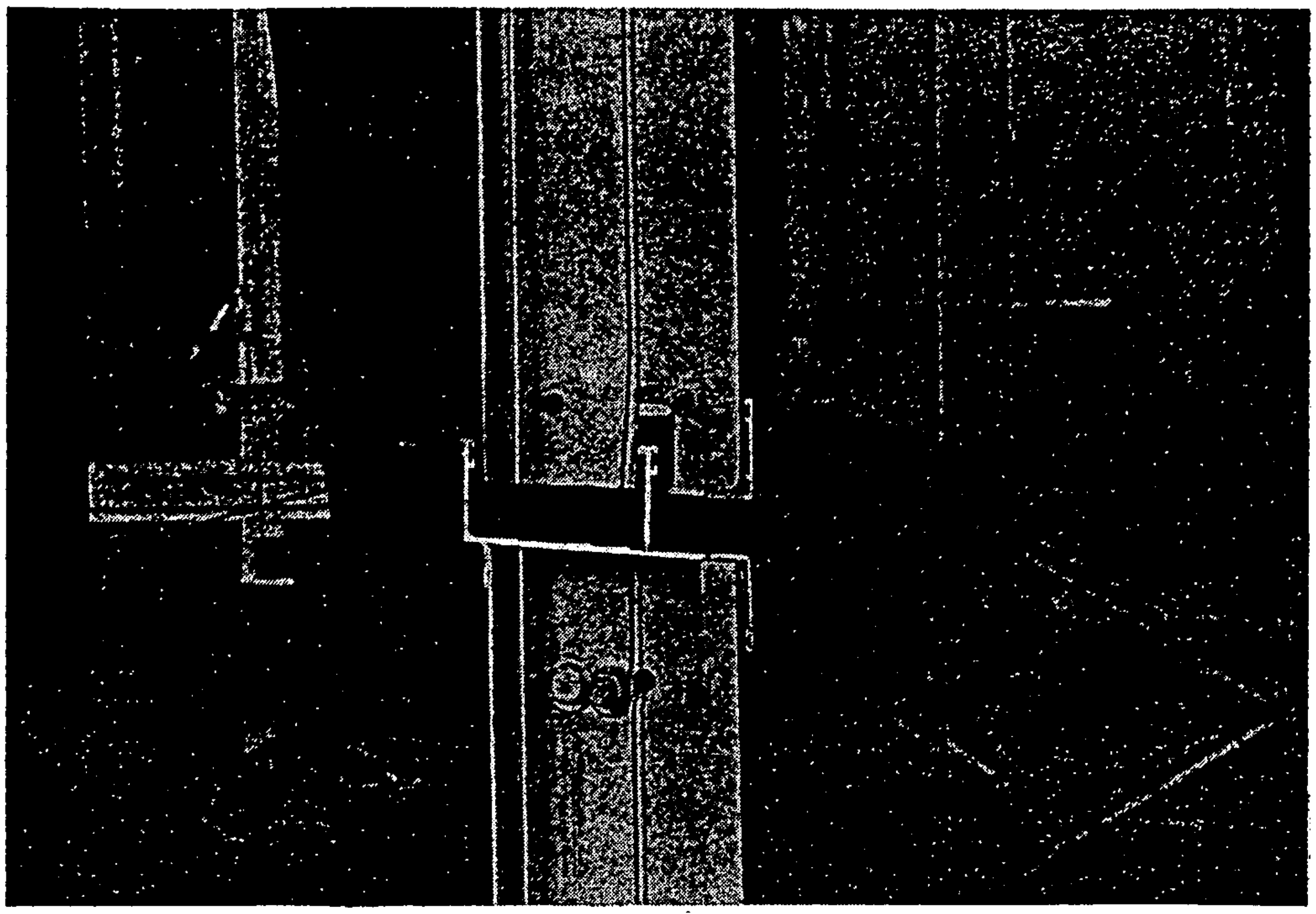

Figure 3 Typical free end of panel

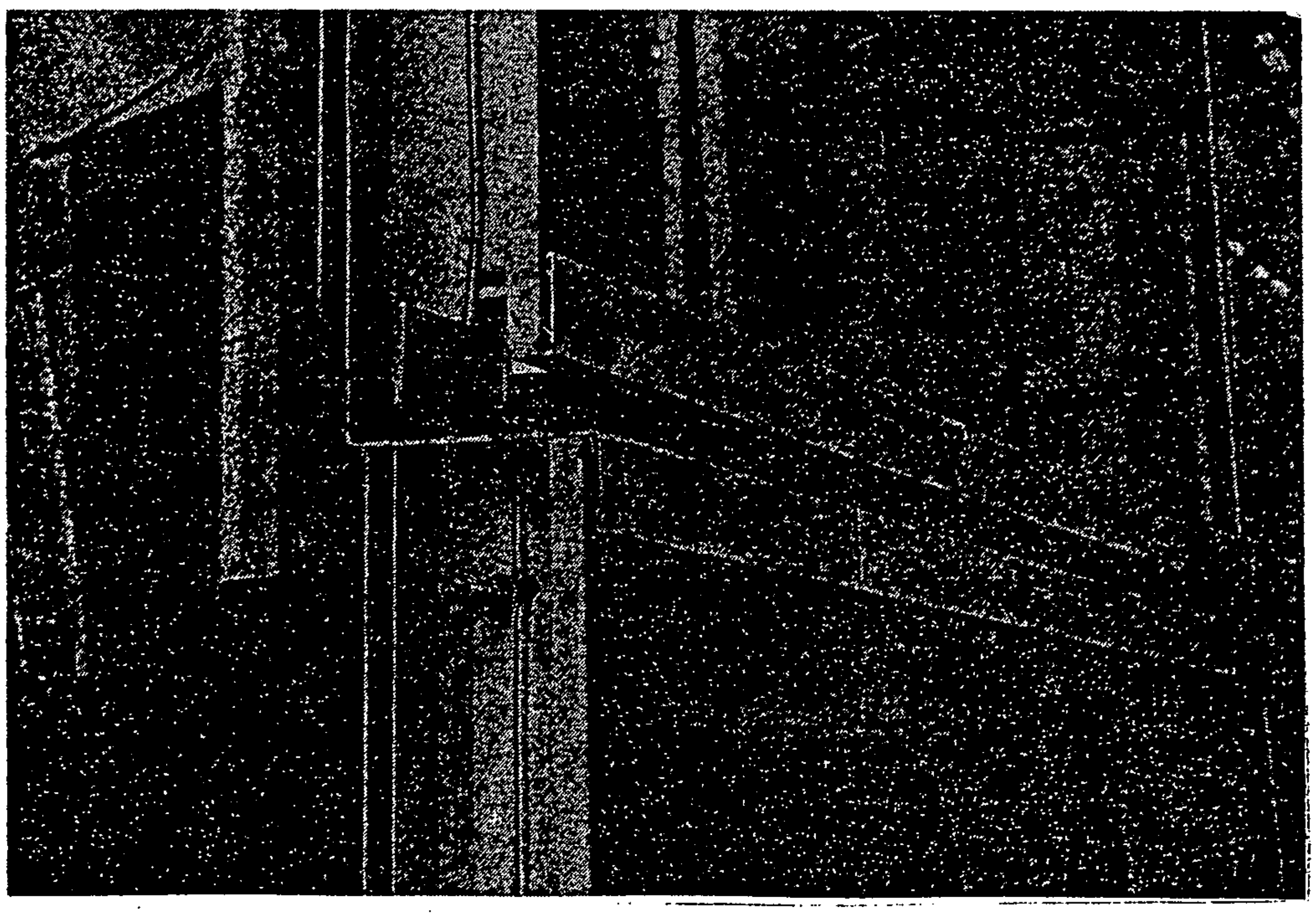

Figure 4 Method for preventing panel misalignment

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