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Seismic Performance of Gamma Brace Frames (GBF) in New Zealand Homes

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The seismic performance of a building (as defined by modern performance-based seismic design) depends on the level of safety provided to building occupants, the cost of required building repairs and the duration of lost functionality for a given earthquake intensity.

The New Zealand Building Code (NZBC) requires that under a design level earthquake (with a 1/500 year return period) a bracing element must provide life-safety to the occupants of the building. Furthermore, for an earthquake that is stronger than the design level (by say 50 to 80%), the building must not collapse. No requirements are given that limit building damage and loss of functionality at or above the design level earthquake. Therefore, it could be interpreted that the NZBC is a minimum standard for seismic design.

The seismic performance of the building is dictated by its bracing system. For house design in NZ, bracing is often provided by plasterboard wall bracing or a mixture of plasterboard wall bracing and other proprietary systems. For mixed bracing systems, the seismic performance of each bracing element cannot be considered in isolation. These elements work together and define the overall building performance (for better or worse).

Under current procedures (termed P21 criteria), the strength of a bracing system for the design level earthquake is defined by measuring the maximum resistance (in terms of BUs) between 8 to 36mm lateral displacement (at the top plate of the wall) [1]. A range of displacements is considered because different bracing systems achieve their maximum resistance at different displacements, depending on the stiffness of the system.

Bearing these points in mind, conclusions can be drawn regarding the seismic performance of the Gamma Brace Frame (GBF). These conclusions are distinct for houses with purely GBF bracing and houses with a mixture of GBF and other bracing systems.

1 Pure GBF Bracing

In general, the GBF appears to exhibit stable force-displacement (termed hysteretic) response with gradually increasing strength at larger displacements and minimal loss of strength up to approximately 3% drift (70mm lateral displacement at the top of the wall).

Because the bracing capacity of the house (provided by the GBF) is defined at less than or equal to 36mm [1], the GBF has reserve displacement capability. This means that the house will be able to undergo an earthquake that is significantly larger than the design level without significant loss of strength. This reduces the probability of building collapse, and occupant death or injury.

Since the GBF has a significantly larger displacement capacity than more common bracing systems, it could be argued that the bracing capacity of the system may be defined at larger displacements than recommended by the current P21 testing criteria (36mm). For example, a 45mm displacement limit may seem reasonable. It is important to note that allowing for larger displacement will result in increased damage to building linings, windows and other non-structural components. However, because the GBF bracing is independent of the internal linings, immediate repair is not required to restore the bracing capacity of the house.

Because the damage to a house under the design level earthquake is dictated to a large degree by the allowable lateral displacement of the bracing elements, it is suggested that if a building owner wants to limit damage then allowable lateral displacements should be restricted. However, to enable performance-based decisions to be made, a relationship between lateral displacement and the expected level of damage is required.

Extensive experimental testing and research commissioned by the Federal Emergency Management Agency (FEMA) in the USA has investigated the fragility of many structural and non-structural elements in modern buildings [2]. One element that is considered is gypsum (plasterboard) wall linings, which make up a large proportion of the damage observed in New Zealand houses during recent earthquakes [3-6]. Furthermore, gypsum wall linings are typically the most displacement sensitive components in New Zealand Houses.

For gypsum wall linings, FEMA [2] provides three damage states at different median lateral displacements, as described in the following table:

Damage state	Description	Median lateral displacements
1. Minor Damage	Screws pop-out, minor cracking of wall board, warping and cracking of tape.	5mm.
2. Moderate damage	Moderate cracking or crushing of gypsum wall boards (typically in corners and corners of openings).	17mm.
3. Significant damage	Significant cracking and/or crushing of gypsum wall boards – buckling of studs and tearing of bottom plates.	28mm.

Considering the findings from FEMA [2], the seismic performance of a house that uses the GBF and is subjected to the design level earthquake can be better defined. Suggested performance levels are presented as shown in the following table:

Seismic Performance	Description	Target displacements
Basic (Minimum requirement to meet the NZBC)	The structural bracing capacity of the house is maintained (and can withstand a significantly larger earthquake). There is likely to be significant damage to internal linings.	36mm.
High (Performance exceeds the requirements of the NZBC)	The structural bracing capacity of the house is maintained (and can withstand a significantly larger earthquake).There is reduced damage to internal linings.	20mm.
Excellent (Performance exceeds the requirements of the NZBC and results in minimal damage after a large earthquake)	The structural bracing capacity of the house is maintained (and can withstand a significantly larger earthquake).There is minimal damage to internal linings.	15mm.

2 Mixed GBF Bracing

Some bracing elements may provide high strength at small lateral displacements (such as long plasterboard walls), while other bracing systems (such as the GBF) may provide higher strength at larger lateral displacements. Yet, for mixed bracing systems in a house, all bracing elements are subjected to similar lateral displacements. This means, it is not appropriate to add the maximum strength of different bracing elements (taken at vastly different displacements) because they will not be achieved simultaneously.

Therefore, the bracing capacity of the GBF for mixed bracing systems should be limited so that the lateral displacement matches the smallest lateral displacement that can be achieved by other bracing systems. For example, if a long plasterboard bracing wall achieves its maximum strength at 15mm, then the bracing capacity of the GBF should also be evaluated at 15mm.

However, current P21 criteria are less strict and allow some variation in the lateral displacement of different bracing systems (8 to 36mm). Hence, to comply with current P21 criteria the bracing capacity of the GBF could be evaluated at 36mm.

The seismic performance of a house with a mixed GBF bracing system is likely to be defined by the non-GBF bracing components. If long plasterboard bracing walls are present, there may be little reserve displacement capacity and the probability of building collapse, occupant death or injury is likely to be larger for earthquakes above the design level (compared to pure GBF bracing). Significant strength degradation of the bracing system may have occurred, which will limit the ability of the house to undergo future earthquakes. Hence, building vacation may be required until the internal plasterboard bracing walls are restored to match the original bracing design.

References

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