ブレース付鋼構造ラーメンに関する実験的研究の計画

Design of an Experimental Program on Chevron-Braced Steel Moment Frames

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Abstract

Braced frames are a widely used structural system recognized for its economy and effectivity in designing safe building environments against earthquakes. The large-scale experimental programs of chevron-braced frames to date have been conducted to suit the typical practices of its sponsoring country for the development and improvement of design guides for their respective structural engineering communities. Japan lacks both recent large-scale braced frame experimental programs and a readily available design procedure for structural designers. An experimental program plan consisting of five large-scale chevron-braced steel moment frame specimens has been designed for the purpose of clearly defining the proportioning and expected behavior aspects of a design procedure for chevron-braced steel moment frames in Japan.

Keywords: Chevron Braced Frames, Steel Structures, Seismic Design,

1. Introduction

Concentrically braced frames (CBFs) are a specific configuration of braced frames in which the intersection of centerlines of members intersect at common work points. The most common of these figurations is the chevron braced frame, which may be described as V-brace and inverted V-brace. These configurations, as well as other common presentations, are shown in Figure 1-2:

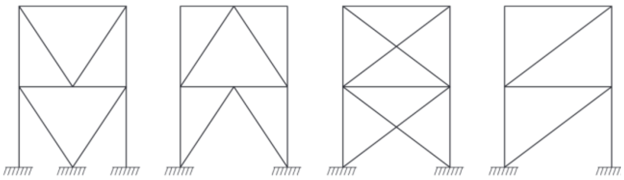


Figure 1-2: Examples of CBF configurations (AISC 341-22)[1)]

Examples of CBF configurations (AISC 341-22).

These braces are used in the structure of buildings for the purpose of increasing building safety and performance during earthquakes. CBFs have also been a subject of research for several countries, and most of the recent research has been conducted on large-scale specimens designed and tested with considerations to the practices and standards of the American Institute of Steel Construction (AISC)[1)] of the United States.

The design of CBFs in the United States, as well as the general steel design and construction practice, differ greatly from that of Japan, and therefore the results of such experiments cannot be so easily utilized for the development of design procedures in Japan.

While the CBF shown in Figure 1-1b is representative and typical of nearly all CBFs designed and constructed in the United States, the CBFs encountered in Japan, vary widely. Brace section size, connection details, the inclusion or omittance of gusset plates, and method of energy dissipation, can differ greatly, even within the same city. An explanation may be that design procedures and design guides for braced frames are unavailable to the structural designers of Japan. Additionally, the current

a) Seen in Otaru, Hokkaido, Japan (courtesy of writer)

b) Seen in the U.S. (Dr. Michael D. Engelhardt)[2)]

Figure 1-1: Chevron braced frames as seen in Japan and the United States design law effectively limits, or even prevents, the use of CBFs in many structures. Of the CBFs observed in Japan, the majority of them are pre-engineered products that were not designed by the structural designer themselves.

Therefore, an experimental program in which five large-scale chevron-braced moment resisting frames (MRFs) were designed. The objective is to propose a design guide for CBFs that includes guidelines for member proportioning, connection detailing, and expected behavior. The results of the experimental program will contribute to the seismic safety of the built environment of Japan by providing design resources for engineers and additional experimental data for the calibration and use in refining non-linear analysis software for high-definition simulation.

2. Research Method

The proposed brace experimental program compromised three key components: literature review, test-setup modification, and the design of the specimens.

Literature review was conducted with particular focus on large-scale experimental programs of both Japan and the United States. The parameters of the specimens were collected for use as validation of the proportions and strengths of the proposed specimens in the designed experimental program. Geometric ratios, including the ratios of overall specimen height to length and the ratio of the length to depth of the beams, braces, and columns were compared to verify the proximity of the proposed specimens relative to other conducted experimental programs.

A component of the literature review also included a comparison of the key features of the United States steel design practice and steel braced frame design that differ from typical practice in Japan. While comparisons of each respective country's building codes have been written about extensively by engineers and researchers of both countries, especially following the intensive collaboration between these trans-pacific structural engineering communities following the 1994 Northridge Earthquake of the United States and the 1995 Hyogoken-Nanbu Earthquake of Japan, additional comparisons, particularly about braced frame design, could be worth merit.

Key features of steel design and construction of the United States that differ from Japan were also examined.[3)] These points include the distinction between the lateral-force resisting system, such as braced frames, MRFs, shear walls, etc., and the gravity resisting system within a steel structure. This results in the U.S. steel system being comprised of mostly simple shear pin connections and concentrated shear stresses that accumulate throughout the diaphragm into specific lines of resistance, which are designed to resist the entire expected force of the structure into only a few designated lateral-force resisting systems, such as braced frames, MRFs, or shear walls. An example line-of-resistance elevation is shown with the labels of beams, braces, and collectors in Figure 2-2. The shaded members indicate members that may be subject to special member detailing requirements.

Due to this design rhetoric, specific detailing requirements are mandated for diaphragms

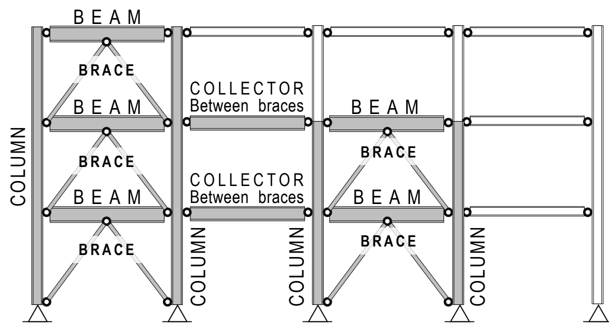


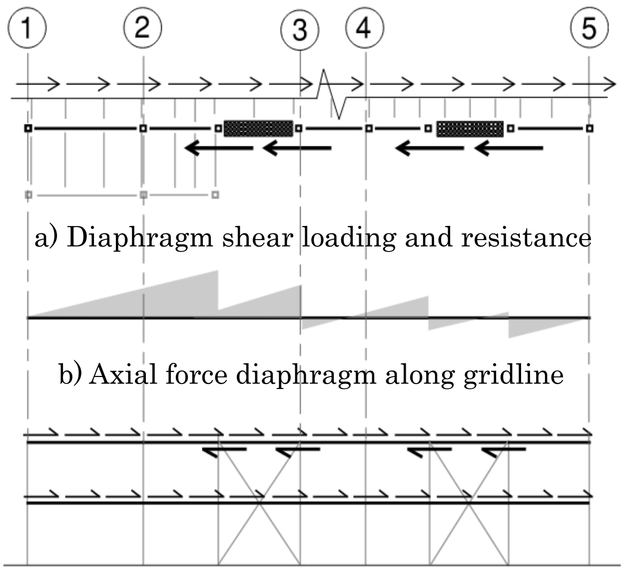
Figure 2-1 Labeled members that may be subject to member requirements depending on brace frame type

and their boundary elements. These boundary elements are referred to as chords and collectors, and special attention is paid to these elements as the imparted shear from the diaphragm and restraint from the lateral-force resisting system result in large axial forces of the member. The accumulation of these forces is summarized in Figure 2-1 for a fictional building plan.

Key features of steel braced frame designs of the United States that differ from typical practice in Japan were also investigated.[4)] The foremost notable difference was that braces can and often are used as the primary and only seismic-force resisting system in a structure.

The placement of these bays of braces results in additional strength checks of the boundary elements of the diaphragm, called chords and collectors. These chords and collectors, as well as the braces and the connection of the braces to the beam and column frame, are all subject to the prescriptive and stringent detailing requirements of the AISC 341.[1)]

The member detailing requirements of braces of the U.S. and Japan are compared in Table 1. Braces are classified by width-to-thickness ratio



c) Elevation with diaphragm shear loading and shear resistance forces

Figure 2-2 Diaphragm shear forces

Table 1: Structural Characteristic Coefficients and Proportion Specifications of Select U.S. and Japanese Braces

	Type / Rank	R or D_s	Ω_o	C_d	Height Limit[a]	b/t	λ
U.S.	Special CBFs	6	2	5	30.5m	HD[b]	λ≤200
	Ordinary CBFs	3.25	2	3.25	NP	MD[c]	n/a
	BRBFs	8	2.5	5	30.5m	≤15.9	n/a
Japan	BA	0.25~ 0.40	n/a	n/a	60m	N/A	λ≤32
	BB	0.30~ 0.40	n/a	n/a	60m	N/A	32<λ≤57 OR 126≤λ
	BC	0.35~ 0.45	n/a	n/a	60m	N/A	57<λ<126

[a] Height limit for Seismic Design Category F
[b] Limiting width-to-thickness for Highly Ductile (HD) Members
[c] Limiting width-to-thickness for Moderately Ductile (MD) Members

of the brace section. The slenderness ratio is not reflected to the structural classes (or rank), unlike Japan, where brace ranking depends on the slenderness ratio but not width-to-thickness ratio. Most notably, member requirements of the AISC 341 define limiting width-to-thickness ratios for moderately ductile and highly ductile members used in these braced frame systems. The difference is alarming because many studies have shown that steel brace rupture is more dependent on width-to-thickness ratios than slenderness ratios.[5)]

This building code and provision review was also conducted so that the proposed specimens would be designed accurately and in accordance to typical practice in Japan in both the analytical and typical construction practice sense. Namely, the Building Standard Law of Japan (BSLJ)[6)] and the AISC[1)] were referenced.

The design of the test setup for the proposed experimental program was also conducted concurrent to the literature review. At the time of schematic specimen conception, the Large Structure Experimental Laboratory of Hokkaido University required significant and extensive modification to develop adequate testing capacity.

This effort included the design and construction of reaction beams, braces, column, wall-attachment steel, and modular portal frames to result in the planned installation of a 2000kN jack at an elevation of 3.5-meters in a reaction floor area of 2.8-meters wide and 12-meters long. As with any experimental program, the limitations of the testing facility resulted in several peculiarities of the proposed specimens.

Specimen design began when the key geometric parameters of the test setup modifications were determined. Although the testing capacity of the facility is 2000kN, the decision was made for the proposed experimental program to include a pilot phase in which the test setup was subjected to only 50% of the capacity of the jack. This is so that the behavior of the test setup can be observed and verified.

3. Research Results

The results of the aforementioned research method resulted in the following proposed experimental program.

A series of five single story, single bay, chevron-braced MRF specimens representing approximately 75% scale was decided. The height of the specimen, measured from the centerline of the beams, was designed to 2850mm, and the length of the specimen, measured between centerlines of the columns, was designed for 5500mm. The resulting brace was designed for an angle of 46.02 degrees. Figure 3 shows the specimen configuration. The properties of the members of specimen one are shown in Table 3.

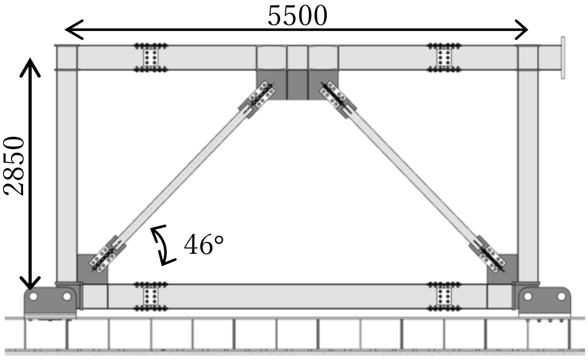


Figure 3 Specimen configuration

The specimens were designed to typical Japanese steel design and construction practices, including the key features of rigid beam-to-moment connections, stub beam splices, cruciform brace connections to gusset plates, and square tube columns. While the column section will remain constant for all specimens, the sizes of the beam, braces, and brace shape will change. Additionally, particular attention will be directed to the interaction of the concrete slab with the brace beam.

The BSLJ[6)] and the AISC[1)] were referenced for member detailing requirements, such as width-to-thickness ratios, slenderness ratios, ductility rankings, connection details, and strength calculations.

The experiments are part of three phases: a pilot trial of specimen one and test-setup verification, a second phase for specimens two through five, and a final phase (outside the scope of this research plan) where the leftover column and beams of the specimens are reused for eccentrically braced frames experimental tests.

4. Conclusion

Braced frames seen in Japan take many shapes, forms, and connection types, which contrast with the unified braced frame designs of some other countries. An experimental program consisting of five nearly full-scale single story, single bay chevron-braced MRF specimens has been designed to produce date that will be used in developing guidelines and procedures for braced frame design in Japan.

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Table 3: Summary of Specimens of Experimental Program

Spec.	Column	Beam	Brace	Ductility	Slab	H (kN)
1	HSS250x250x9	H300x150x6.5x9	HSS101.6x5.7	HD/FA	No	561
2			HSS139.8x4.5	MD/FA	Yes	653
3			HSS139.8x4.5	MD/FA	No	730
4			H-125x125x6x9	MD/FA	No	662
5		H500x200x10x16	HSS101.6x5.7	HD/FA	No	626