Modal Analysis and Design of Long Span Special Truss Moment Frames

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Abstract - *It is very challenging to use very long span structure with steel moment frames and braced frames for sporting and industrial venues. Requirement of new designs are essential for these types of applications. STMF (Special Truss Moment Frames) addresses such design requirements with efficient plastic hinge concept. This research focused on a novel STMF design and its parametric analysis. An initial design was started with ASCE 2010 code and the same model is used for the analysis. Modal analysis is conducted to find out the natural frequency of the frames and is followed with cyclic analysis. A harmonic excitation is also given to the moment frames to study about the dynamic effects of the system. Moment deflection curves and hysteresis loops are developed for STMF to complete the study. STMFs generally have higher structural redundancy compared to other systems because four plastic hinges can form within the chords of 1 truss girder. The redundancy are often further enhanced if web members are utilized in the special segments. Simple connection details are needed for the girder-to-column connections. The truss girders are often used over longer spans , and greater overall structural stiffness are often achieved by using deeper girders. The open webs can easily accommodate mechanical and electrical ductwork.*

***Key Words*: Special Truss Moment Frames, Plastic Hinge, Hysteresis Loop, Harmonic Excitation, Special Segments**

1. INTRODUCTION

Long-span structures are commonly used in sporting and industrial areas thanks to the necessity for giant openings, which can't be provided by steel braced frames. Steel moment frames, are often provide open space, become very flexible and need large sections to regulate their drifts when an extended span is employed. Therefore, moment frames are impossible to use when a span exceeds approximately 12 m. A special truss moment frame (STMF) may be a seismic force-resisting system, which will accommodate both an outsized open space between columns and a steel truss girder better than a beam. Open webs of the trusses can accommodate the utility and mechanical ducts to travel through it, hereby providing greater architectural freedom. It can dissipate earthquake energy through flexural yielding of the chord members and intermediate vertical web members within the center section of the truss girder, called special segment (SS),where as members out- side of the SS are designed to stay elastic. When diagonal web members are present within an SS, axial yielding and buckling of those diagonals also help dissipate energy.

STMFs generally have higher structural redundancy compared to other systems because four plastic hinges can form within the chords of 1 truss girder. The redundancy are often further enhanced if web members are utilized in the special segments. Simple connection details are needed for the girder-to-column connections. One other advantage of using STMF systems is that the truss girders are often used over longer spans and greater overall structural stiffness are often achieved by using deeper girders. additionally, the open webs can easily accommodate mechanical and electrical ductwork. As a consequence, this technique is gaining popularity within the us, especially for hospital and commercial buildings. Research work administered at the University of Michigan led to the formulation of design code provision. Current design practice generally follows elastic analysis procedures to proportion the frame members. Therefore, it's possible that story drifts and yielding within the special segments might not be uniformly distributed along the peak of the structure and should be concentrated during a few floors causing excessive inelastic deformations at those levels. Thus, the intended deformation limits and yield mechanism might not be achieved when an STMF is subjected to strong earthquakes.

In recent years, seismic design has been gradually moving toward a more direct performance-based design approach, which is meant to supply structures with predictable and controlled seismic performance. to realize this goal, knowledge of the last word structural behaviour, like nonlinear relationships between forces and deformations, and therefore the yield mechanism of structural systems are essential. Therefore, the specified global yield mechanism must be built into the planning process. In current practice, the performance-based seismic design for a replacement structure is administered during a somewhat indirect manner. it always starts with an initial design consistent with conventional elastic design procedures using applicable design codes, followed by a non- linear static pushover assessment. Usually, an iterative process between design and assessment follows. Moreover, as mentioned in FEMA 440, this procedure still has difficulty in predicting reasonably accurate structural behaviour during a serious earthquake.

Sanputt Simasathien, et.al.During this research, double-HSS members were proposed for the chord and web members of STMFs rather than double-angle, double-channel, or single-HSS.Double-HSS can effectively delay flange local buckling and enhance rotational ductility thanks to reduced width-to-thickness ratio. A full-scale STMF sub assemblage with double-HSS as truss members was tested. Testing results indicate that using double-HSS truss members may be a viable alternative for STMFs in high seismic regions.

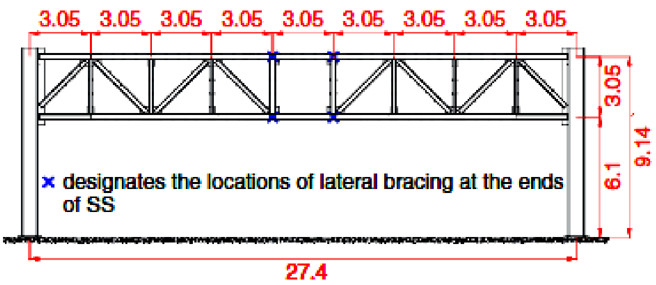

Fig-1 Dimension and elevation of STMF (Meters)

2. Finite Element Modeling

2.1 General

The special truss moment frame (STMF) may be a relatively new sort of steel framing system suitable for top seismic areas. The frames dissipate earthquake energy through ductile special segments located near the mid-span of truss girders. STMFs generally have higher structural redundancy compared to other systems because four plastic hinges can form within the chords of 1 truss girder. The open webs can easily accommodate mechanical and electrical ductwork. The STMF showed larger stiffness and strength but smaller ductility compared with the instant frames.

2.2 Geometry and Material Properties

In figure 1, The length of the specimen is 27.4 m and depth of the specimen is 3.05 m. Height of the building is 9.14 m. Spacing of purlins is 3.05 m. Spacing of truss is 9.14m.Special truss moment frames are made of steel sections of density of 7850kg/m^3 young's modulus and poisons ratios are 200 GPa and 0.3. Bilinear isotropic hardening is used to reproduce the plastic behavior of materials. Chart 1 shows the bilinear Isotropic hardening of the material used for STMF.

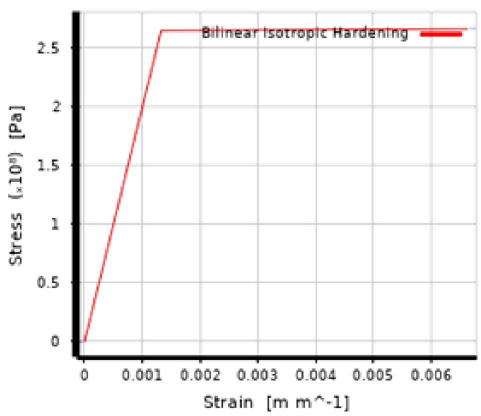

Chart-1: Bilinear isotropic hardening

Table -1: Size and Properties of Members

Member	SIZE	Young's Modulus (Gpa)	Poisson's Ratio
Column	C920x970	200	0.3
Panel zone	C920x970	200	0.3

Top SS	2C380x74	200	0.3
Bottom SS	2C380x74	200	0.3
Chord 1-2	2C380x74	200	0.3
Chord 3-4	2C380x74	200	0.3
Diagonal 1	2C380x74	200	0.3
Diagonal 2-4	2C310x52	200	0.3
Vertical 1-3	2C310x52	200	0.3
Intermediate	2C150x19.3	200	0.3

2.3. Finite Element Model

In the finite element analysis mesh was selected after the grid independence study. There are 462 elements and 914 nodes are used to create the finite element models of STMF. The selected three-dimensional model of STMF was developed by finite element software to demonstrate the behaviour properly. SOLID 186 elements used for the 3D modeling of STMF. It is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. This element exhibits plasticity, hyper elasticity, creep, stress, stiffening large deflection and large strain capabilities Connection between the diagonal member and vertical members by gusset plate. There are 58 contact regions in the special truss moment frames.

2.4 Meshing

Meshing divides the whole component into finite number of small elements as per requirement. Size of element must be as small as possible to achieve accuracy. In this analysis, fine mesh was adopted to achieve maximum accuracy in results. Solid models are converted into a finite element model after meshing.

2.5 Load and Boundary Conditions

Fig-3 shows the boundary conditions of STMF. To simulate the real condition, STMF were analyzed with fixed support at one end to restrain axial deformation and earth gravity is applied to the special truss moment frames. Standard Earth Gravity direction is defined along one among three global or local frame of reference axes. Body will move within the same direction of the applied gravity. The bilinear isotropic hardening rule was used for the finite element analysis special truss moment frame. The loading protocol for chord or vertical member component tests in this study was derived from AISC loading protocol as specified by story drifts ratio (SDR) for testing moment frame [AISC 341 (AISC 2016)]. The SDR history was first applied to the prototype full-scale STMF. The tests were done according to the corresponding member rotations at the specified SDR of the prototype STMF.

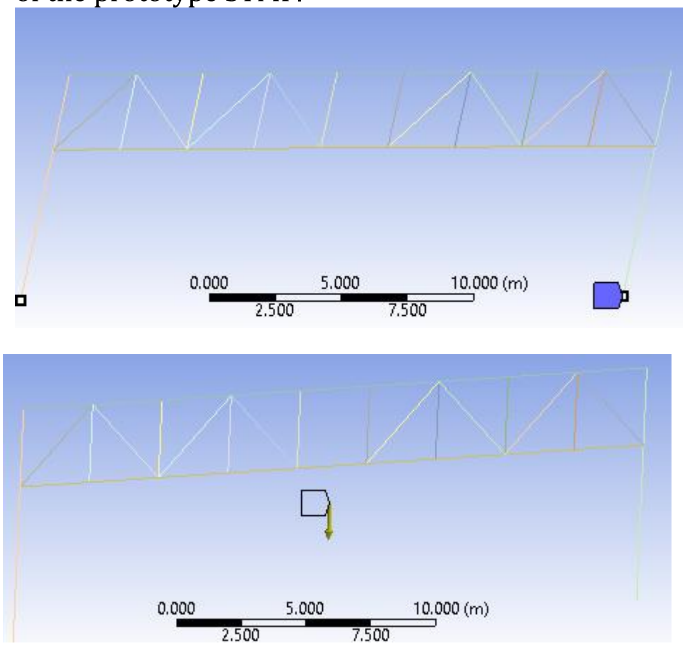

Fig-2: Boundary Conditions of STMF

3. Result and Discussion

3.1 Modal Analysis of STMF

Total deformation of special truss moment frames are shown below.

Table 2 frequency given in the model

Mode	Frequency(Hz)	Deformation(Mm)
1	0	162.2
2	0	162.2
3	4.7918	7.1083

4	6.4607	10.567
5	6.6114	9.687
6	8.5168	8.1767

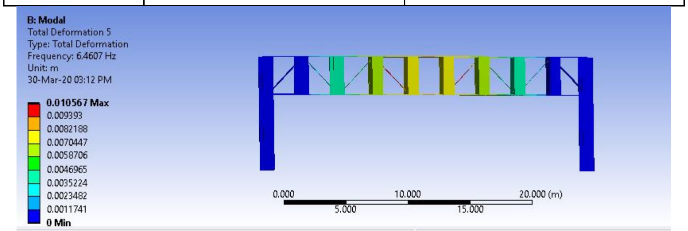

Fig-3: Deformation at 6.46Hz of STMF

The maximum deformation occurs at the frequency of 6.46 Hz .above the frequency the resonance occurred.

3.2 Seismic Analysis o f Special Truss Moment Frames

In dynamic analysis, the structure is governed by the additional inertia force produced by the acceleration load applied over small time interval. In addition, a damping factor contributes significantly to the structural response. Transient dynamic analysis (sometimes called time-history analysis) may be a technique wont to determine the dynamic response of a structure under a time varying load. In this work, all nonlinearities mentioned under static analysis are allowed in transient analysis.

Earthquake is amongst the most terrifying of all natural phenomenon's. Striking without warning, and seemingly coming out of nowhere, these challenge our inherent assumptions about the stability of the very planet we live upon. Any shaking of the world , whether lasting for minutes or just for seconds, seems eternal to those that experience it. A mild quake may inspire no more than passing interest, but a powerful one can wreck awesome devastation.

Seismic analysis may be a subset of structural analysis and is that the calculation of the response of a building structure to earthquakes. It is a part of the method of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent.

3.2.1 Uttarakhand earth quake

A magnitude 5.1 earthquake struck India, at depth of 16.1 km (10 mi), near Rudraprayag district within the state of Uttarakhand on February 6, 2017. it's belong to the zone of IV , the High Damage Risk Zone and covers areas susceptible to MSK VIII Tremors were felt continuously for thirty seconds in capital Delhi NCR and neighbouring Gurgaon, Punjab and other parts of north India. One person was injured, with panic scenes round the epicenter. Many cracks in buildings were reported. The acceleration time plot of Uthrakhad earthquake is employed during this work for transient analysis. Acceleration time history of the 2017 uthrakhand earthquake commonly mentioned because the Great Hanshin earthquake. Duration of earthquake is 41s.

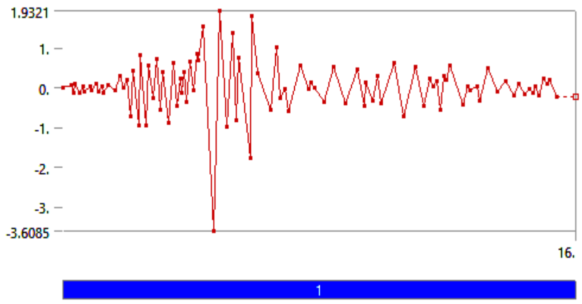

Chart-2: Acceleration time graph of Uttarakhand earthquake

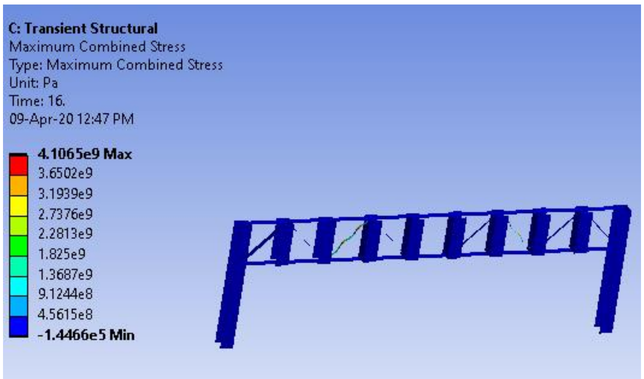

Fig-4: Combined stress of STMF

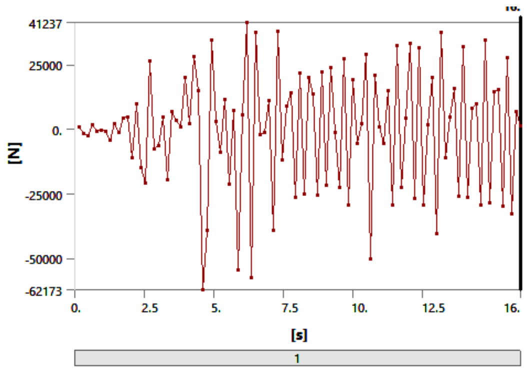

Chart-3: Force reaction graph

The maximum. deformation obtained is 0.13141 m. The maximum force obtained from the graph is. 41237 N at 6.1782 secs. The maximum combined stress in the analysis of special truss moment frame is found to be 4106.5 N/mm² which is higher than the yield strength of structural steel.

3.3 Performance of STMF for Harmonic Type of Vibrations.

Harmonic response analysis computes the response of the structure to a load that features a sinusoidal time-history. Solves the time-dependent equations of motion for linear structures undergoing steady-state Vibration. All loads and displacements vary sinusoidally at an equivalent frequency.

$F_i = F \sin(\omega t + \varphi 1)$

$F_j = F \sin(\omega t + \varphi 2)$

Analyses can generate plots of displacement amplitudes at given points within the structure as a function of forcing frequency. The structure will have some natural frequencies of its own, which are computed by a Modal analysis, and when the harmonic load frequency matches the natural frequency, the response are going to be larger than when the harmonic frequency is higher or less than the natural frequency.

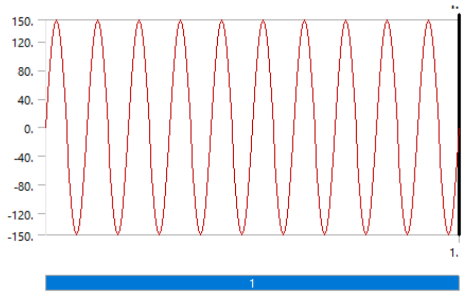

Chart-4: Input data of harmonic excitation

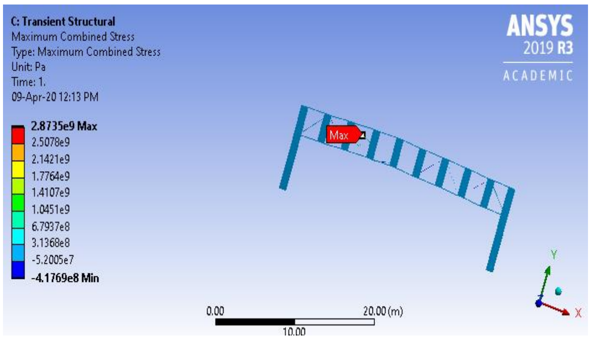

Fig -5: Combined stress of STMF

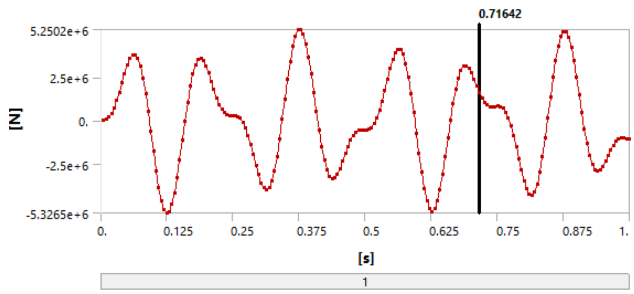

Chart-5: Force Reactions of STMF

The deformation of the structure during harmonic excitation is about 163.85 mm and the maximum force reaction is about 5250.2 kN at 0.375 sec. The maximum combined stress in the analysis of special truss moment frame is found to be 2873.5 N/mm² which is higher than the yield strength of structural steel.

4. CONCLUSIONS

A typical conclusion are often drawn from this study and may be applied for full scale structure . because the model will react similarly to the particular building if the model's natural frequency matches with the building's natural frequency . However the conclusion

- When analysing the Special truss moment frame using modal analysis ,the natural frequency of the STMF obtained is 6.64 Hz above this value of other vibrations causes resonance.
- In modal analysis deformation of the structure is only about 10.56 mm which is less than the ordinary frames .
- In earth quake regions the deformation is only about 131.41 mm it much less than when compared with the ordinary building frames.
- The STMF can resist the severe damages in the buildings

- The harmonic excitation of STMF is less when compared with other truss frames.
- The combined stress on the STMF is higher than the yields strength of the structural steel
- From the stress analysis of the building frame the structure is safe
- The structure is used in any hazards regions.

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