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A STUDY AND RELIABILITY ANALYSIS OF COMPOSITE STEEL STRUCTURE UNDER DIFFERENT TRUSS ELEMENT

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Abstract:

Composite materials have been used extensively to build truss structures owing to their remarkable properties. Composite truss structures have attracted tremendous research interests due to their superior strength and performances, and have been utilized in the construction of civil structures. Compared to other structural materials, such as concrete, structural timber composite steel has a considerably higher variability of the strength properties both within and between members. The variability within a timber member is not considered in engineering design, where each member is treated under the assumption that it is homogeneous, i.e. the strength is assumed to have a constant low value along the member. The advantage of the low probability that high stresses coincide with low strengths is however not accounted for and may give an extra safety margin. The reliability of structural systems has to be verified against failure caused by extreme effects, such as fire and seismic effects. To the best of the authors' knowledge, there is a lack of studies in the literature on comprehensive reliability calculation of complex structural systems; the available studies mainly deal with the reliability calculation of simple, separated elements. This paper compares and provides a study of various levels of research work done in computational structural analysis. The crust of our review focuses on the analysis of truss, complex or simple because truss is the most widely used and fundamental building block of any structure.

Introduction:

Truss have during evolution specialized in resisting its natural environment e.g. to stand snow and wind loads. In sawn timber the conditions for the composite steel material differ compared to the living tree. The branches that collected the sunshine for the photosynthesis are now forming knots with locally disturbed grain directions and are seen as defects in design of composite steel structures. The research concerning reliability of composite steel structures is fairly young. The natural defects in structural timber arise special issues that in particular must be addressed in reliability studies:

- The variability of the strength properties is large.
- Difficulties in predicting some failure modes. Strength grading of structural timber may consequently be inaccurate for some of the failure modes.
- The knowledge of the variability is not documented to the same extent as competitive materials.

The current steel design process consists of two steps, an analysis to determine internal actions such as forces and moments, and a design check for adequate strength, for all individual members and connections. Component-based design is a simplistic process that could be improved to increase efficiency and economy. Advanced analysis completes the analysis and design check in a single step, thereby saving time in the design process. Additionally, advanced analysis directly models factors affecting the structure, such as geometric imperfections and residual stresses, enabling the user to accurately model the structure.

Literature review:

1. **Christensen and Baker (2017)** the three levels of structural reliability analysis

and methods of design are: The "exact" probability of failure is determined using full probabilistic description. Iterative calculations with an idealisation of the failure domain and simplified representation of the variables. Design methods using partial safety factors related to characteristic values of the actions and resistance variables. The codes of today are at Level 1 where the partial safety factors are determined on the basis of a Level 2 analysis.

2. **U. Radoń (2016)** presented simple steps for performing pushover analysis using SAP2000 software. The SAP2000 static pushover analysis capabilities, which are fully integrated into the program, allow quick and easy implementation of the pushover procedures prescribed in the ATC-40 and FEMA-273 documents for both two and three-dimensional buildings.

3. **A. Dudzik, U. Radoń (2015)**, extended pushover analysis to cover planeccentric buildings and took the three-dimensional torsional effect into account. Because of torsional deformation, floor displacements of the building will consist of both translational and rotational components. Torsional effect can be particularly damaging to elements located at or near the flexible edge of the building where the translational and rotational components of the floor displacement are additive. In view of the damage observed in many eccentric buildings in past earthquakes.

4. **Mwafy (2014)** Comparison with 'dynamic pushover' idealized envelopes were obtained from incremental dynamic collapse analysis. This involved successive scaling and application of each accelerogram from 12 experiment buildings, followed by assessment of the maximum response, up to the achievement of the structural collapse. The results of over one hundred inelastic dynamic analyses using a detailed 2D modeling approach for each of the twelve RC buildings were utilized to develop the dynamic pushover envelopes and compare these with the static pushover results.

5. **Hasan R. (2013)** presented a simple computer-based push-over analysis technique for performance-based design of building frameworks subject to earthquake loading. The technique was based on the conventional displacement method of elastic analysis. Through the use of a plasticity-factor that measured the degree of plastification, the standard elastic and geometric stiffness matrices for frame elements (beams, columns, etc.) were progressively modified to account for nonlinear elastic-plastic behavior under constant gravity loads and incrementally increasing lateral loads. The method accounted for first-order elastic and second order geometric stiffness properties, and the influence that combined stresses have on plastic behavior.

6. **Menjivar and Pinho (2012)** extended the pushover method to asses the performance of 3D irregular RC structures. The issues of diaphragm effects, loading profiles and incremental dynamic analysis were studied. The modeling based on Displacement Based and Force Based Pushover was compared. Conventional verses Adaptive Pushover results have been compared and were found to be close.

7. **P. Obara, W. Gilewski (2010)** conducted studies of structural retrofitting of various facilities and had defined the entire process in simple steps from Preliminary Vulnerability study, Selection of Performance objectives, Site characteristics, Building characteristics,

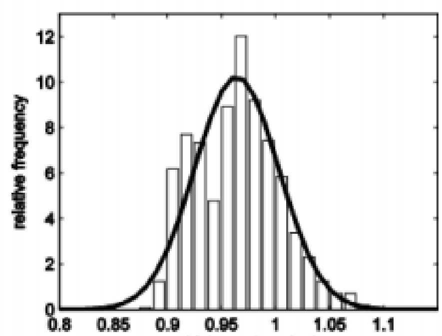
Selection of retrofit procedures and Analysis techniques.

8. **Agarwal, Y. Murotsu (2008)** compiled a series on identification of seismic damages in RC buildings in Bhuj, highlighting damages due to soft storey failure, floating columns, plan and mass irregularity and quality of construction material. Damage to various structural elements, infill walls, exterior walls, water tanks and parapets, staircases and elevators were studied in detail. Effect of earthquake on code designed structures was also examined. Effect of structural irregularities of strength, stiffness, mass, geometry and plan, on the performance of RC buildings during earthquakes was examined and recommendations for same were stated.

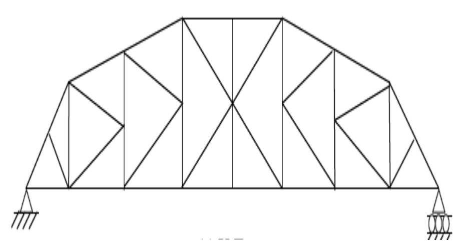
Methodology:
Methods used:

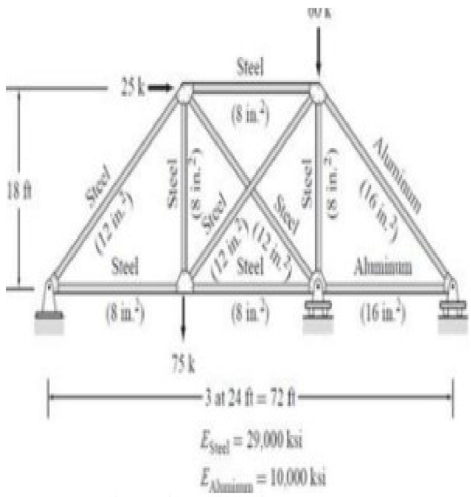
- **Fire analysis methods:** The steel structures are extremely low resistance to high temperatures. The most important mechanical properties of steel are yield strength and modulus of elasticity.
- **The reliability analysis methods:** The reliability of a structure is its ability to fulfil design purposes for some specified reference period. In the fundamental case the loading is described by a single random variable E and the strength by a single random variable N. The probability of failure Pf is then defined as ∫ Ω = f Pf fN,E (N, E)dNdE
- **The structural systems method:** To carry out reliability analysis according to structural system method it is essential to define properly all possible failure modes. In order to determine the reliability of this approach it is necessary to set KAFM (kinematically admissible failure mechanism)

For dual system of frame-core wall structure, core wall is the key lateral load resistant member bearing more than 80% earthquake shear force. In order to improve the ductility of the core shear walls steel columns of HM340×250×9×14 were embedded at the four corners of the core wall and the intersections of longitudinal and transversal core shear-walls which would also be considered as the second proof to the shear wall in avoidance of potential consecutive collapse owing to the degradation of its vertical bearing capacity from the serious cracking of the concrete under rarely occurring earthquake. On the other hand the embedded steel column also enhance the anchorage of the floor truss/beam. While as, in order to strengthen the inelastic deformation capacity of the longitudinal coupling beams carried steel trusses and ensure the integrity character of the core wall, steel shapes were encased inside the coupling beams, which were connected with embedded steel columns forming the embedded steel frames within the longitudinal core shearwalls.

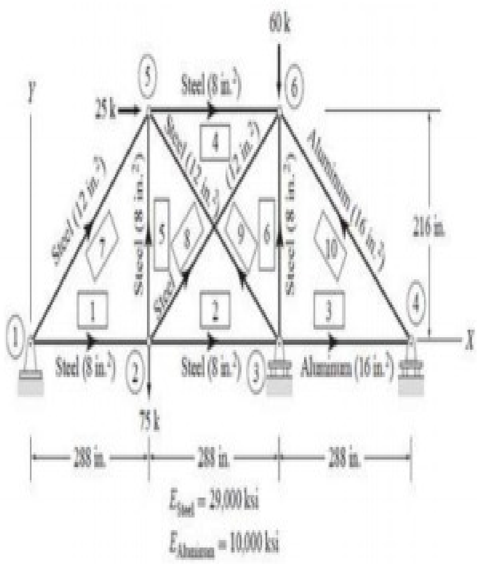


fit of HSS wall thickness


Truss pattern



Proposed Truss Structure



Analytical model of truss element

RESULTS:

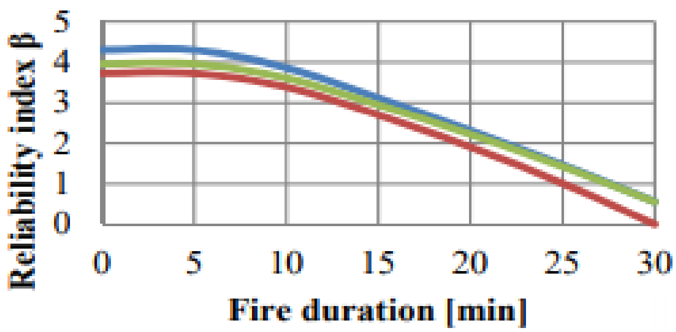
Analysis for two types of trusses (statically determinate and indeterminate), shown in the figure 2 was carried out using MES3D program. In the table, the profiles of elements and the effect of actions are shown, where (-) means compression. All elements were assumed to be made from S275 steel. The only load was the dead load p=3kN/m applied to the top flange, and it was converted to concentrated forces in the nodes. It was assumed that all elements were heated from each side and were under influence of standard fire curve. Spray-applied mineral fibre with the thickness of 1.5cm was assumed as insulation. This material is characterized by the following parameters: density ρp=800kg/m3, specific heat cp=1700J/(kgK), thermal conductivity λp=0.2 W/(mK).

Probabilistic characteristics of random variables

Type of truss	Random variable	Expected value	Expected value	Standard deviation	Distribution type
Statically determinate	**Cross section area-A**	**0.00106 m^2**	**6%**	**0.0000636 m^2**	**normal**
Statically indeterminate		**0.000373 m^2**		**0.00002238 m^2**	
Statically determinate/ indeterminate	**Yield strength f_y**	**275 000 kPa**	**8%**	**22 000 kPa**	
Statically determinate	**Effect of action- E**	**8 kN**	**6%**	**0.48 kN**	
Statically indeterminate		**5.25 kN**		**0.315 kN**	

Reliability index for statically determinate structure

Fire duration [min]	FORM	SORM Importance Sampling		System reliability		Element's reliability
0	4.30	4.30	4.25	4.11	3.73	3.96
5	4.30	4.30	4.25	4.11	3.73	3.96
10	3.86	3.86	3.81	3.72	3.39	3.6
15	3.12	3.12	3.04	3.06	2.70	2.95
20	2.31	2.31	2.25	2.17	1.91	2.22
25	1.47	1.47	1.41	1.48	1.02	1.43
30	0.57	0.56	0.55	0.60	<0	0.53



Graph shows reliability vs fire duration

Conclusions:

The proposed paper concerns different methods of the reliability analysis of steel structures exposed to fire. Two types of trusses (statically determinate and statically indeterminate) were considered. The fire analysis was carried out in MES3D program, it was assumed that structures were insulated with the spray-applied fiber and were exposed to the fire described by the standard time-temperature curve. We propose a structural analysis program which will have all the above features and in addition to that a graphical user interface will be there for easy visualization. For statically indeterminate structure opposite result- the effect of statistical reinforcement was noticed - the reliability index was much higher according to system analysis. It means that using approximation or simulation methods, that seems to be easier, is safety for statically indeterminate structures. In the case of statically determinate structure it is recommended to support analysis with second level method by system analysis, what is not difficult task.

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