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RANDOM RESPONSE OF STEEL HALL SUBJECTED TO THE DYNAMIC EXCITATION BY THE GENERALIZED ITERATIVE STOCHASTIC PERTURBATION TECHNIQUE

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ABSTRACT: This work aims to analyze the random response of steel halls subjected to dynamic wind excitation. The investigated object has recently been erected in central Poland and its mathematical model has been created in Abaqus 2017 software. The model includes the warp of beam elements involved in the structure which adds additional value to this work. Dynamic analysis has been performed with the Hilber-Hughes-Taylor algorithm and recovered responses undergo further approximation in polynomial form for probabilistic analysis. Several uncertainties of mechanical and environmental nature are investigated. Generalized Iterative Stochastic Perturbation Technique has been contrasted with Monte Carlo Simulations and Semi-Analytical Approach. Conclusions from this comparison are discussed in this paper.

Keywords: stochastic finite element method, reliability analysis

5. INTRODUCTION

It is commonly practiced to design steel hall structures with use of quasi-static equivalent of some actions which in fact are of dynamic nature. Steel structures can exhibit significant slenderness. Additionally to that, taking into account the specific characteristic of I-beams including warp of beams cross-sections can bring some motivation to furtherly investigate the structural response of steel halls under dynamic excitations. In this work the wind action will be undertaken as an example of a dynamic excitation which is commonly substituted by the quasi-static equivalent. The study will include the investigation of stress-related and displacement-based responses of some steel hall structure with tapered I-beam profiles.

6. STRUCTURAL ANALYSIS

Investigated structure taken upon in this work is some steel hall recently erected in central Poland. The mainframes of this structure have been modeled as tapered I-beam profiles described by the yield strength of 355 MPa and elasticity modulus of 210 GPa. Mainframes have been spaced by the distance of 7.60 m and main girders have been inclined by 5 degrees from horizontal orientation, creating the shape of the pitched roof. The connection between column and main girder has been modeled as a fixed joint.

Supports of the columns at the foundation level have been modeled as pin joints. The overall geometry of investigated structure has been shown in Figure 1.

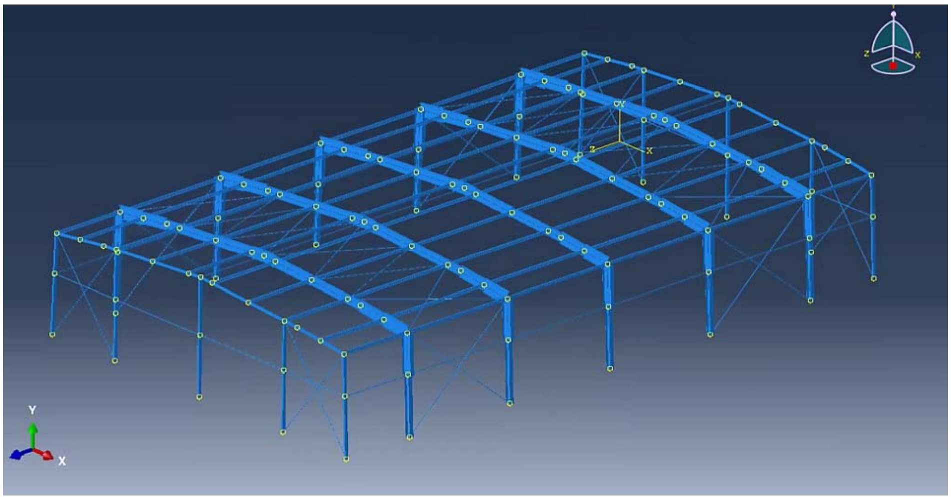

Fig. 1. Steel hall geometry overview.

A numerical model of investigated structure has been created in Abaqus 2017 software. Finite Element Method (FEM) analysis has been performed with the implementation of beam elements which consists of 7 degrees of freedom (D.O.F.) at each node so that warp of open section elements has been included in the recovered structural responses. Dead load and environmental loads have been introduced into the model by the Eurocodes statements (EN 1991-1-3 2003, EN 1991-1-4 2010). Additionally, the structure undergoes dynamic wind excitation in 10 minutes time intervals as shown in Figure 2. The dynamic structural response has been found by the Hilber, Hughes and Taylor (1977) integration and the dynamic responses in form of nodal displacements and internal forces have been recovered every 5 seconds of dynamic wind action. The time-step of calculation has been set as 0.10 s.

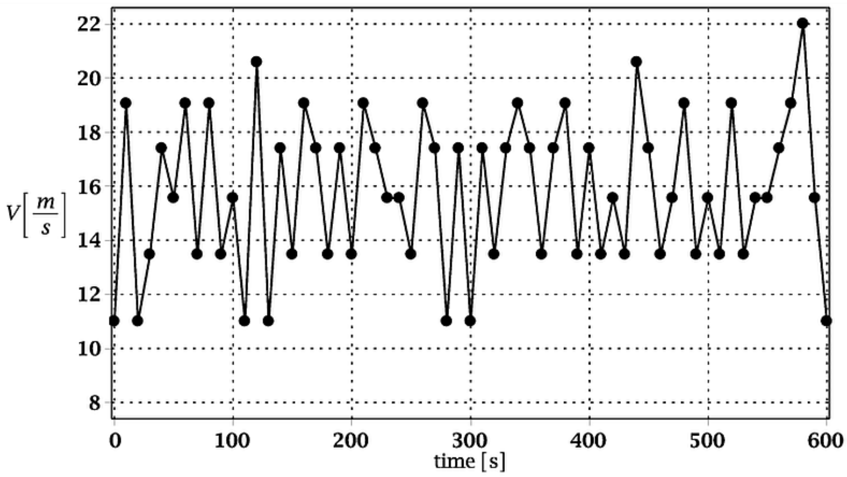

Fig. 2. Dynamic wind spectrum.

The Hilber-Hughes-Taylor solver is based upon some time discretization regime, where the structural displacements and velocities in the given time step are found based upon the velocities and accelerations in the previous time step as:

$$\begin{cases} x_{i+1} = x_i + \Delta t \cdot \dot{x}_i + \left(1/2 - \beta\right) \cdot \left(\Delta t\right)^2 \cdot \ddot{x}_i \\ \dot{x}_{i+1} = \dot{x}_i + \left(1 - \gamma\right) \cdot \Delta t \cdot \ddot{x}_i \end{cases} . \quad (1)$$

Coefficients *beta* and *gamma* in (1) are directly associated with numerical damping involved in this method. This numerical damping coefficient can be taken within a range of <-0.3, 0.0> and the lower this parameter is, the higher the numerical damping. In this work, the greatest numerical damping has been involved which had been also proposed in previous works of authors.
The abovementioned dynamic analysis has been repeated for 11 realizations of each uncertain parameter involved in this work. Those include random wind velocity, random snow load, random elasticity moduli, and random thickness of webs and flanges of I-sections. These uncertainty sources have been considered separately and for each of them, 11 realizations have been described around its expectation as shown in Table 1. Underlined values refer to the expectation of each uncertainty, where all of them have been described by the Gaussian distribution with an input coefficient of variation equal to 0.10.

Table 1. Representative uncertainty sources

No.	Elasticity Moduli GPa	Peak wind Velocity m s^{-1}	Snow Load kN m^{-2}	Thickness of webs and flanges (Coefficient) [-]
1	189.0	20.87	0.6480	0.900
2	193.2	21.10	0.6624	0.920
3	197.4	21.33	0.6768	0.940
4	201.6	21.56	0.6912	0.960
5	205.8	21.78	0.7056	0.980
6	<u>210.0</u>	<u>22.00</u>	<u>0.7200</u>	<u>1.00</u>
7	214.2	22.22	0.7344	1.02
8	218.4	22.44	0.7488	1.04
9	222.6	22.65	0.7632	1.06
10	226.8	22.86	0.7776	1.08
11	231.0	23.07	0.7920	1.10

Having recovered discrete values of structural responses in form of displacements and stresses at chosen nodes of the structure in 10 minutes spectrum, the polynomial approximation in form of the Weighted Least Squares Method has been taken upon. Those responses have been approximated in form of 10^{th} order polynomials including triangular weighting function. Prescribed weights to each realization are as follows: <1, 2, 3, 4, 5, 6, 5, 4, 3, 2, 1> where the greatest weight has been assigned to the expectation of each parameter under consideration (compare with Table 1.) The procedure of Structural Response Function (SRF) approximation has been developed in a self-written algorithm in Maple software.
Those SRF's have been furtherly used in another self-written algorithm to approximate the random structural responses. To pursue this aim, the Generalized Iterative Stochastic Perturbation Technique (SPT) has been involved also with Monte Carlo Simulations (MCS) and Semi-Analytical Method (SAM) where the last two, have been introduced as referential techniques.
Stochastic Perturbation Technique is based upon classical Taylor expansion, which for single input random variable can be presented as follows (Kamiński 2013):

$$U_i(E) = U_i\left(E^0\right) + \sum_{j=1}^{n} \frac{\varepsilon^j}{j!} \frac{\partial^j U_i}{\partial V^j}\bigg|_{E=E^0} \cdot (E-E^0)^j \ , \qquad (2)$$

$$i = X, Y, Z .$$

Expectations, variances, and also probabilistic characteristics utilizing higher-order central moments are furtherly discussed in this paper. The first two central moments naturally have been also found crucial for FORM reliability assessment based upon the Cornell concept found in Eurocode 0.

7. RESULTS

Probabilistic results obtained in this series of tests exhibit remarkable consistency and for that matter, every expectation of structural response recovered for each uncertainty source followed the dynamic wind velocity spectrum. Additionally to that, the discrepancies in between SPT and referential techniques have been found marginal as shown in Figure 3. Similar observations can be made regarding characteristics referring to coefficients of variations and reliability indices.

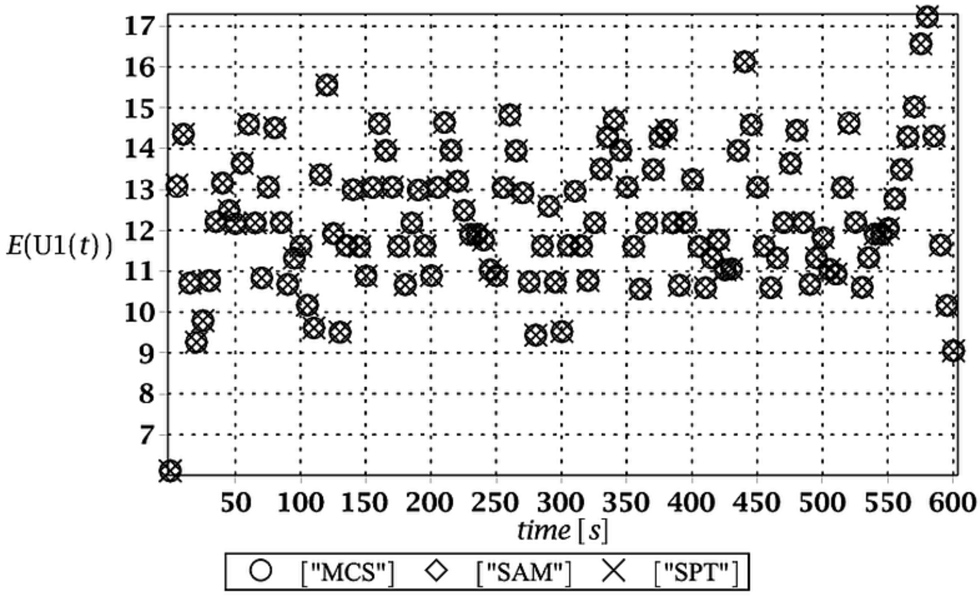

Fig. 3. The expected value of horizontal displacement of the top of the column for uncertain snow load.

8. CONSLUSIONS

From these series of tests, it has been concluded that HHT integration with maximum numerical damping allows performing further WLSM approximation in polynomial form from which, random structural responses have been approximated. Random structural response approximation and further probabilistic approach by the SPT itself have been found also accurate when contrasted to referential techniques.

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