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Modeling Criteria for FE-Simulation of Shock Transfer Processes in Concrete Structures

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Key Words: *Impact loads , shock wave transfer, wave shape grasp points, mesh refinement, low-pass filter element size, convergence element size*

ABSTRACT

Shocks and high frequency excitations on building structures due to impact loads (impact of wreckage and heavy objects from collisions, transport operations or explosions), but especially due to a postulated aircraft crash, lead to feasibility problems and large expenditures at safety-related installations in the designing of technological systems accommodated inside the building structures. A rational and cost-effective qualification and verification of the operability of such systems requires reliable information about the nature of the induced excitations (structural responses) to be anticipated at their particular areas of installation in the impacted structure. The analytical derivation of realistic and reliable structural responses requires the application of suitable, robust mathematical models as well as a critical evaluation of all influencing factors on entire shock transmission path, from the area of impact to the site of installation of the affected plant component or system.

The present paper addresses especially to the required FE mesh refinement adequate to short duration and impact type of loading. In order not to mix various influences and for better understanding of the (mesh refinement-depended) wave propagation phenomena in real concrete structures physical uncertainties, for instance uncertainties in material properties (modulus of elasticity, yield strength, etc) as a consequence of the randomness in nature, were for the present not taken into consideration.

Intense scientific studies (related to static loadings) has been devoted in the past to these research directions in several studies and the results were published in a number of papers (Schueller [1], Wiberg [2], Charmpis and Schueller [3]). However, it is known that research in the directions of FE mesh refinement and quantitative uncertainties modeling has been progressing in parallel and practically independent research routes have been followed. Both of aforementioned scientific areas: the effect of quantitative uncertainties modeling as well as the influence of mesh density on the results obtained using FE models were especially examined in [3].

Despite extensive studies and computational analyses of impact-induced shocks performed using FE models of variable refinement limited and insufficient experimental results to date have precluded complete investigation and clarification of several "peculiarities" of shock transmission phenomena in FE models. This refers mainly to the divergence of numerical results obtained using FE models (versus analytically derived

results)observed, especially if neglecting the consideration of the required refined (element-type-specific) discretization ratio, of FE models as well as to the attenuation and dispersion behaviour of the dynamic response results of building structures with large dimensions and therefore large distances between the load impact areas and the component anchoring locations. Experiences as well as numerical analyses of shock transmission occurrences have indicated that FE models behave like low -pass filters with a certain wave passage frequency range up to a specific cut-off frequency. The various wave passage frequencies and their cut-off frequencies are especially dependent on the type of propagating waves, the direction of wave propagation in respect of the FE nodal matrix and on the travelling wave frequency.

By series of recently performed systematic parametric studies [4] of typical substructures (beams, plates, shells and scaled model structures) using a broad variation of model discretization the suitability limits of FE - models and - approaches for the determination of local and global impact-induced dynamic response were investigated .

The concept of the mathematical models in the above-mentioned parametric studies was based in each model discretization case (and selected typical load function durations) on a discretization variant required to represent the basic mode shape amplified by the corresponding impact load function, with a sufficient number of data points identifying the vibration form of this mode (wave shape grasp points). The results (time histories and response spectra of displacements and accelerations) of the calculations performed for this discretization variant and by further more refined models were than presented and compared for characteristic observation points of the substructures .

The outcome of the analyses and comparisons of the above-mentioned results is that for the structures discretized with various model refinement a change in the arrival times of the shock waves and the variation of the magnitude of amplitudes (due to the associated element- size - influenced damping character) can be clearly anticipated . The larger the mesh size, the greater the delay in the arrival time of shock waves and the more detectable the element-length damping influences.

By comparing and evaluating the extensive results determined for the typical substructures (beams, plates and shells) by applying a wide variation of refinement it was possible to identify unambiguous a passing element size (low-pass filter element size) of FE models, which are characterized by the fact that beginning by certain element size (convergence element size) L_c the structural responses (time histories and spectra) determined still in good agreement and display a satisfactory convergence with results obtained by more refined FE model meshing. Any further refinement do not result in any changes of the results. On the basis of this "convergence criterion", the opportunity to specify the largest suitable mesh grid for discretizing the respective substructures was given the use of which enables results to be obtained within the range of reliability.

Summarizing the above, it can be stated that even if a comfortable wave grasp approach is applied (e.g. wave acquisition by 9 or more grasp points) - it is still not possible to specify an appropriate size for a finite element (or the mesh of FE models) which would ensure reliable results for given impact loads. The element sizes determined by this way are demonstrably too large. However the performed parametric studies mentioned above using various mesh refinement shows that appropriate FE model discretizations for handling impact problems can be specified, and reliable results obtained, on the basis of the convergence element size L_c. Empirical relationships based on this information are proposed for future applications by which the allowable element size ($L_c = c_{l,s} / k f_n$) may be determined on the basis of the length or shear wave velocity propagation $c_{l,s}$, the frequency ($f_{n)}$ of the highest mode to be considered and of an element - type – specific “convergence correction factor” k

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