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Advanced dynamic & crash simulation of lightweight profiles for design of roadside infrastructure

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Abstract

Many research works recently have attempted to use different computational and numerical simulation techniques to model the material thermal large deformation processes for the design of high performance profiles in new roadside infrastructure designs. The material processes for the lightweight crash-capable parts are among the most delicate processes for the material scientist and designing engineers. The forming and extrusion of lightweight alloys involves thermal effects, large deformation, complex geometries and free surface boundaries. The conventional approach towards the simulation of extrusion process using Finite Element (FE) or Finite Volume (FV) has serious short comes even when updated Lagrangian, Eulerian or ALE techniques are employed. During past decades, there has been considerable effort to simulate the whole extrusion process by splitting it into steady state (using Eulerian technique) and transient (using Updated Lagrangian technique) processes.

The damage initiation, progression and also failure of lightweight hollow profiles during crash are a result of accumulated damage under plastic deformation. Based on the damage theories, as the loading condition is changing for the material, a plastic deformation may take place which would progressively increase the damage in the component. The accumulated damage would ultimately result in the failure of the cross-section. There are different numerical models to calculate the damage evolution, fracture initiation and also its propagation using continuum and/or discrete damage techniques. In the present study, following an in-depth study of material processing and its absorption capacities, folding modes and geometric/production constrains; a frame work has been setup to develop and test an optimised aluminium extruded profiles for best dynamic and crash performance characteristics. The numerical dynamic simulations (including fatigue, vehicle buffeting …) and virtual crash performance of lightweight hollow profiles have been considered for the design of new generation of roadside signals, lighting posts… for future.

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The complicated mathematical basis of large deformations, plasticity, contact and folding have been developed and special attention has been devoted to the plastic deformation, rate dependency and tailored yield locus. To assess the dynamic performance and energy absorption of these profiles, a full transient dynamic analysis can be performed using a time history dynamic loading. The new absorbing component design has been checked and verified using a result of carefully-setup experiments work and also advanced explicit simulation runs. One of the main contributions of this paper is to show the applicability and reliability of the numerical simulation approach for the crash performance of new lightweight roadside entities.

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Keywords: Roadside infrastructure; process simulation; lightweight extruded profiles; crash & dynamic analyses

1. Introduction

To perform an accurate simulation of lightweight alloys for dynamic performance, due to its complicated multi-physical aspects, it is essential to use an advanced and innovative numerical approach. For the material processes, the method should be capable of dealing with phase changes, thermal energy transfer, large deformation and also solid stress-strain state conditions. The Eulerian, Lagrangian, ALE and mesh-less techniques have been developed and used by different researchers to model the thermo-deformation process. In Lagrangian (and also updated Lagrangian with adaptive re-meshing) description the thermo-deformation process, the process of large deformation of a body is pictured as a material flow where each material particle (cell) carries its own properties such as density, etc. As the extrusion front advances its properties may change in time and space and the simulation technique has to take into account these transient spatial changes.

Many research works in the last couple of decades have attempted to use different computational and numerical methods to model the material processes involving thermal large deformation phenomena. The material processes for the lightweight crash-capable parts are among the most delicate processes for the material scientist and designing engineers. The extrusion of lightweight alloys involves thermal effects, large deformation, complex geometries and free surface boundaries. The conventional approach towards the simulation of material forming using Finite Element (FE) or Finite Volume (FV) has serious short comes even when updated Lagrangian, Eulerian or ALE techniques are employed. During past decades, there has been considerable effort to simulate the whole forming process by splitting it into steady state (using Eulerian technique) and transient (using Updated Lagrangian technique) processes.

The damage initiation, progression and also failure of alloys during crash are a result of accumulated damage under plastic deformation (Rice et al. 1969, Lemaitre 1985, Neukamm 2009). Based on the damage theories, as the loading condition is changing for the material, a plastic deformation may take place which would progressively increase the damage in the component. The accumulated damage would ultimately result in the failure of the cross-section. There are different numerical models to calculate the damage evolution, fracture initiation and also its propagation using continuum and/or discrete damage techniques.

2. Numerical techniques for material process

Different numerical simulation techniques have been established and used by different researchers in recent decades, to model the nonlinear large thermo-deformation processes. As the forming process advances, its properties may change in time and space. The procedure of describing the entire material flow by recording the detailed histories of each cell is the Lagrangian description. This means that in the Lagrangian algorithms, each individual node of the computational grid follows the associated material particle during the advance of extrusion front. Hence, The Lagrangian description allows an easy tracking of forming process (free surfaces) and interfaces between different parts of computational model. It also facilitates the treatment of materials with history-dependent constitutive relations, however, its main weakness is the inability of the method to follow large distortions of the computational domain without recourse to frequent re-meshing scheme (computationally expensive task).

While, in the Eulerian approach, rather than following each material cell (i.e., extrusion front), the evolution of the material flow properties at every point in space, as time varies, can be recorded. This means that the material flow properties at a specified location depend on its spatial location and on time. The computational mesh is fixed in this approach and the material moves with respect to the grid. In the Eulerian description, large distortions of the material motion can be handled with relative ease, but generally at the expense of precise interface definition and the resolution of material flow details. Since both of these methods have some shortcomings (updated Lagrangian and Eulerian methods), a hybrid technique has been developed that combines the best features of both the Lagrangian and the Eulerian approaches. In the Arbitrary Lagrangian–Eulerian (ALE) description, the nodes of the computational mesh may be moved with the material front in normal Lagrangian fashion, or fixed in Eulerian manner or be moved in some arbitrarily specified way to give a continuous rezoning capability. More comprehensive discussion about the Lagrangian, Eulerian and ALE approaches can be found in engineering handbooks (Bathe 1996, Zienkiewicz et al. 2005).

2.1. Meshless Techniques

The problems of computational modelling for industrial processes (i.e., extrusion application) have been growing in recent years. For challenging simulation of manufacturing processes such as extrusion and moulding it is required to deal with thermal large deformations of the computational grid. These challenging problems limit the use of conventional computational methods (Lagrangian, Eulerian, ALE…) since the underlying basis of these methods are relied on a computational grid. The strong discontinuities which are natural consequence of the extrusion process are not coincided with the original mesh lines. The most practical strategy for dealing with these moving discontinuities is to carry out adaptive re-meshing in each computational step. The evolution of new computational grid is carried out so that mesh lines remain coincident with the discontinuities throughout the evolution of transient extrusion front.

The goal of meshless technique is to remove the numerical constraints of computational grid by constructing an approximation kernel based on entire points (nodes). Although in many meshless methods recourse is required to be taken to some type of computational grid in the course of transient simulation, the moving discontinuities can usually be modelled without re-meshing (which is computational expensive). This would open the way for the efficient solution of large classes of process problems which are very naturally awkward with grid-based methods.

The meshless Element-Free Galerkin (EFG) technique, which is capable of handling process simulation with arbitrary and complex geometries using only nodal data, has gained popularity in recent years (Belytschko et al. 1996, Chen et al. 1996, 1998, 2001). The method can be applied to elasticity, heat conduction, large deformation and fracture mechanical problems with much less computational efforts. The EFG technique is developed using the principal of diffuse element technique (Belytschko et al. 1996) which has been introduced earlier for generalising the finite element method. For EFG technique, Moving Least-Squares (MLS) interpolants are used to construct a function for the variational principle (weak form) where dependent variable and its gradient are continuous in the entire domain. The MLS interpolant of displacement function $u^h(x)$ can be written as (Belytschko et al. 1996),

$$u^h(x) = \sum_j^m p_j(x) a_j(x) = \boldsymbol{P}^T(\boldsymbol{x})\boldsymbol{a}(\boldsymbol{x}) \tag{1}$$

where $p_1(x) = 1$ and $p_j(x)$ are polynomial functions (with single term) in the coordinate system. For the two dimensional quadratic basis function $\boldsymbol{P}^T(\boldsymbol{x}) = [1, x, y, x^2, xy, y^3]$**,** *m=6* and the coefficients $a_j(x)$ are fuctions of $\boldsymbol{x}$. The $\boldsymbol{a}(\boldsymbol{x})$ can be obtained at any coordinate point *x* by minimizing a weighted discrete norm,

$$J = \sum_i^n w_a(\boldsymbol{x} - \boldsymbol{x_i})[\boldsymbol{P^T}(\boldsymbol{x_i})\boldsymbol{a}(\boldsymbol{x}) - u_i]^2 \tag{2}$$

where *n* is the number proximity points which the weighted function $w_a(\boldsymbol{x} - \boldsymbol{x_i}) \neq 0$ and $u_i$is the nodal value of at u at $\boldsymbol{x} = \boldsymbol{x_i}$. For each of the nodes in the computational domain, the domain of influence (kernel influence) is defined by a circle (in two dimensional) of neighbourhood nodes.

2.2. Numerical implementation of EFG

The numerical implementation of the meshless EFG technique for extrusion application can be started by defining influence sub-domains for each node as circle (two dimensional) and sphere (three dimensional) in the active coordinate system as (see figure 1),

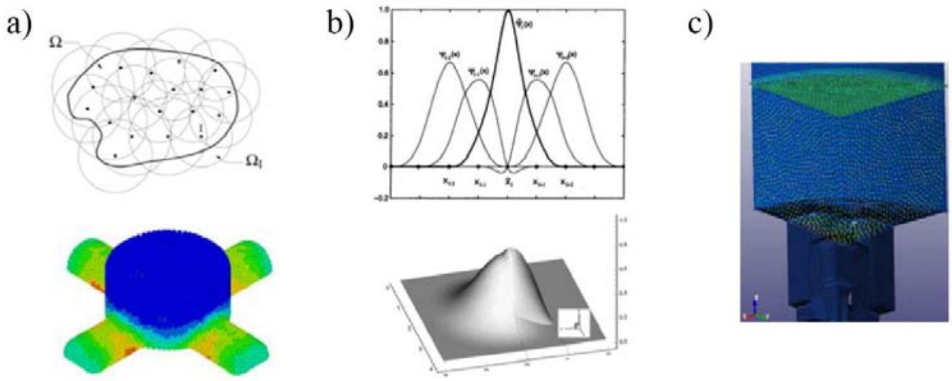


Fig. 1 (a) sub-domains definition, nodes 3D representation; (b) Spline kernel functions for EFG; (c) EFG numerical model.

The above mentioned functions are called the B-spline kernel function which defines the weighting function for each point in the computational domain.

3. Advanced crash simulation and damage modelling

Based on the nonlinear transient dynamic theory and theory of damage accumulation and failure, as the loading condition is changing for the material, a plastic deformation may take place which would progressively increase the damage in the component. The accumulated damage would ultimately result in the failure of the cross-section. There are different numerical models to calculate the damage evolution, fracture initiation and also its propagation using continuum and/or discrete damage techniques (Horr et al. 2014, Angermeier 2014).

During the past decades, dynamic simulations and crash problems of vehicle frames and components have been considered for the design of lightweight structural component by some authors, and special attention has been devoted to the energy absorption, dynamic stability, damping, material strength (crash behaviour) and fatigue characteristics. The nonlinear dynamic analysis and vibration effects along with energy absorption of crash-capable lightweight components (through stable folding), has attracted many researchers attention in recent years. One of the most important lightweight components in a design of crash-capable member is the front longitudinal. It is generally responsible for a large proportion of the energy absorption in a vehicle in the case of a frontal crash. A number of different tools to study crash, nonlinear dynamical systems and energy absorptions have been developed in the last decades using implicit and explicit techniques. The explicit finite element technique has been extensively used in nonlinear transient dynamic simulations for crash analysis. The size of time steps for explicit integration is limited by the numerical stability of the analysis. Hence, an explicit dynamic simulation using conventional finite element method usually employs many small steps. For the explicit dynamic analysis the weak form of the momentum equation can be written as,

$$\int_{\Omega} \rho \ddot{u}_i \upsilon_i d\Omega + \int_{\Omega} \sigma_{ij} \frac{d\upsilon_i}{dx} d\Omega = \int_{\Omega} f_i \upsilon_i d\Omega + \int_{\Gamma_s} g_i \upsilon_i d\Omega \tag{3}$$

where u_i and υ_i are the displacement and variation components, σ_{ij} are the stress components, ρ is the mass density, f_i are the components of body forces per unit volume, g_i are the components of surface tractions specified on part of the boundary Γ_s for the domain Ω. The acceleration of system can be computed based on the nodal acceleration as,

$$\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{bmatrix} = [N] \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \tag{4}$$

where $[N]$ is the interpolation matrix. More comprehensive discussion about the nonlinear explicit dynamic simulation technique can be found in engineering handbooks (Bathe 1996, Zienkiewicz et al. 2005). The development of proper material, damage and failure modelling is one of the first requirements for successful dynamic and crash simulation. One of the first pioneers in continuum damage mechanics were Kachanov, Rice and Tracy (Rice et al. 1969). Their damage models were based on mathematical formulation for creep and spherical voids in continuum materials. Gurson (1977) has extended the theory of damage evolution, using spherical voids in a continuum, by investigating the evolution of ductile damage due to growth and nucleation of voids in an elasto-plastic material. In his ductile damage model, the material yielding is coupled with a scalar damage variable and hydrostatic stress. Some modification to Gurson ductile damage model has been proposed by Tvergaard and Needleman (Needleman et al. 1992) in which three material constants are introduced.

The more recent damage model is proposed by Lemaitre (1985) in which a micro-mechanical model is developed to simulate the void growth, nucleation and coalescence in continuum. The phenomenological Lemaitre damage model is based on thermodynamic approach where a scalar damage variable is depending on the ratio of damaged area over the total surface area. The load carrying capacity of the material is fading by degradation of the stiffness matrix due to damage accumulation. A “Generalized Incremental Stress State dependent damage Model” (GISSMO) has also been proposed by Neukamm et al. (2009) recently. It is based on combination of incremental material instability, failure description and localisation. The path dependencies of the instabilities are taken into account along with the failure description. The nonlinear damage accumulation in the material is introduced in this model and the experimental test data is fitted into the model using accumulation exponent.

In the discrete (discontinuous) damage models, a discretised numerical model can be developed where the element (particles) are modelled with strong discontinuity. There are two different approaches in discrete damage modelling, namely; finite element approach with strong discontinuity and secondly, mesh-free and particle methods. In the finite element method with strong discontinuity, the crack (i.e., macro cracks) is modelled explicitly. The mesh-free and particle methods have recently been developed using Smoothed Particle Hydrodynamics (SPH), Reproducing Kernel Particle Method (RKPM) and Lattice-Particle Model (LPM). These mesh-less methods have already proven to be an effective tool in nonlinear mechanical simulations and nonlinear elasticity (Belytschko 1996). There are different mathematical formulations to explain the large deformation (folding) of material under external loading conditions (i.e., Deformation theory, Flow theory…). The stress, strain and strain-rate state in the material model can be calculated based on mathematical description of elasto-plastic behaviour. There are different ways of modelling reversible and irreversible deformations in the numerical simulation using mathematical theories. The yield criterion is one of the most popular methods of determining the state of stress and strain in the metals. One of the first generalised yield functions has been proposed by Hill (1948) as;

$$f_y = H.(\sigma_{11} - \sigma_{22})^2 + F.(\sigma_{22} - \sigma_{33})^2 + G.(\sigma_{11} - \sigma_{33})^2 + (2N.\sigma_{23}{}^2 + 2L.\sigma_{31}{}^2 + 2M.\sigma_{12}{}^2) - 1 \tag{5}$$

where *F, G, H, L, M* and *N* are six anisotropic parameters. For the study herein, different yield criteria based on the recent work by MatFEM (2008) has been used as,

$$\sigma_{eq} = k_1.(|X_1 - X_2|^{m_1} + |X_2 - X_3|^{m_1} + |X_3 - X_1|^{m_1})^{\frac{1}{m_1}} + k_2.(|Y_1|^{m_2} + |Y_2|^{m_2} + |Y_3|^{m_2})^{\frac{1}{m_2}} \tag{6}$$

where X_1, X_2 and X_3 are the principal components of the stress vector X which can be calculated from the stress tensor σ and coefficient matrix *C* as described in MatFEM manual (2008). The formulation requires the definition of fifteen independent parameters (m_1, m_2 ...) for the yield locus in the general stress state. For the plane stress state (constant or no stress in third direction), the number of independent parameters are reduced to eleven. To account for tension-compression asymmetry condition, the yield locus would be adjusted depend on the stress state (tensile or compressive stress) as;

$$\sigma_{eq} = \sigma_{eq}(\sigma, k) \qquad k = k(\sigma,\ k_T\ ,\ k_G\ ) \tag{7}$$

where the set of coefficient k_T, will be used for tension stress state ($\sigma_3 \geq 0$) and the set of coefficient k_C, would be used for compression case. For other cases (second and forth quadrants) the coefficients would be interpolated to reach at a set of tension-compression coefficients.

The hardening curve can be applied to the material model using true stress and strain ($\varepsilon_t = ln\frac{L_1}{L_0}$ and $\sigma_t = \sigma_{eng}e^{\varepsilon_t}$ where σ_{eng} is the engineering stress). It is well known that the hardening properties of materials can be isotropic, anisotropic or kinematic depend on the intrinsic plastic (slip) material behaviour. Different analytical strain hardening rules can be used to describe the evolution of yield locus and flow potential in plastic zones. The material model used herein is capable of taking into account the isotropic, kinematic and anisotropic as well as combination of isotropic-kinematic hardening.

4. Passively safe design – lightweight design

The improvement of existing road infrastructure and the future design of safe and innovative highway gantries and signs is one of the important aspects of future transportation outlooks. The gruesome number of road fatalities/injuries as well as its psychological and economic impacts requires continuing practical research to improve the safety of roadside structures and facilities (see figure 2). The passively safe design concept for the roadside structures has attracted many attentions among researchers and design engineers in the last couple of decades. Different methods have been employed to modify the design of conventional roadside structures (i.e., steel, wooden…) to make them passively safe. The policy makers for transportation strategies and automotive industries have made great efforts to meet more stringent criteria for the occupant passive safety in an accident scenario.

The materials used for the design of passively safe gantries and signs should have at least minimum specific strength as well as high fracture toughness (without progressive fracture), and crash resistance to absorb the dynamic energy in an accident scenario. The safety of vehicle passengers involved in the accident as well as the interference of the damage roadside structure with the oncoming highway traffic need to be considered rigorously. The use of lightweight alloys (aluminium, magnesium…) for the design of large lattice roadside structures has been considered by many design engineers in recent years and special attention has been paid into energy absorption and dynamic properties of these materials. The safe design of frame structures under impact loading (i.e., car crash) enable the structural components to be strong enough under its functional loading combinations, but at the same time, in an event of a car crash, it starts to deform and absorb energy by means of buckling and changing shape forms (using fuse joints, unzipping riveting system, …).

Energy absorption categories	Occupant safety level	Speeds			
		Mandatory low speed impact test 35 km/h		Speed class impact tests 50, 70 and 100 km/h	
		Maximum values		Maximum values	
		ASI	THIV (km/h)	ASI	THIV (km/h)
HE	1	1,0	27	1,4	44
	2	1,0	27	1,2	33
	3	1,0	27	1,0	27
LE	1	1,0	27	1,4	44
	2	1,0	27	1,2	33
	3	1,0	27	1,0	27
NE	1	1,0	27	1,2	33
	2	1,0	27	1,0	27
	3	0,6	11	0,6	11
NE	4	No requirement	No requirement	Non-harmful equipment	

Fig. 2. European standard EN 12767, 200,7energy absorption demands, aluminium gantry profiles and crash tests/simulation results.

There have been many research studies to improve the dynamic behaviour and energy absorption of lightweight alloys using various techniques (Yia et al. 2001, Leea 1999). The dynamic behaviour of lightweight structural component and also automotive components can be characterized for both cast alloys and extruded profile. The use of lightweight alloys would reduce the overall mass of the structure which subsequently changes the dynamic behaviour of highway structures for vehicle buffeting and environmental gust effects. The design pressure graphs for the vehicle buffeting, developed in previous section, along with the novel spectral element technique can be used to design a passively safe lightweight highway structures.

4.1. Fatigue assessment and dynamic analysis

To verify the novel simulation technique for the design of large gantry structure, a series of verification case studies have been carried out. A complete set of initial geometric modelling and static, eigen (exact spectral-eigen), mode superposition and also local three dimensional FE analyses can be performed to design a high performance large lightweight road structure (i.e., gantry). Wind gust pressures are an important design parameter for large highway lattice structures, cantilever gantries and also large roadside traffic signs. CFD simulations (steady state and/or transient) can be employed to evaluate dynamic wind pressure and large vehicle buffeting loadings where the complex air flow behaviour in and around the wake of highway structure can be better evaluated. One of the main advantages of CFD simulation for the vehicle and wind-induced vibration of large structures is its detailed pressure distribution and also flow visualizations. Figure 3 shows the typical streamline around a gantry traffic sign, pressure distribution on a cantilever gantry and its corresponding deformation.

A three dimensional geometry model of a gantry structure can be generated, meshed and exported (as mesh boundaries) into a CFD software for wind gust calculation. All the setup parameters need to be defined within CFD simulation domain including, analysis type (steady state or transient), domain interfaces, material properties, turbulence modelling, atmospheric boundary layer condition and the size/shape of the virtual wind tunnel. To study the effects of directional wind (wind rose) and its overall combinational influence on the design of large gantries, a robust numerical procedure has been set up to evaluate the required design conditions. More comprehensive discussions on the design of large gantries under wind gust pressure loading can be found in Horr et al. 2009.

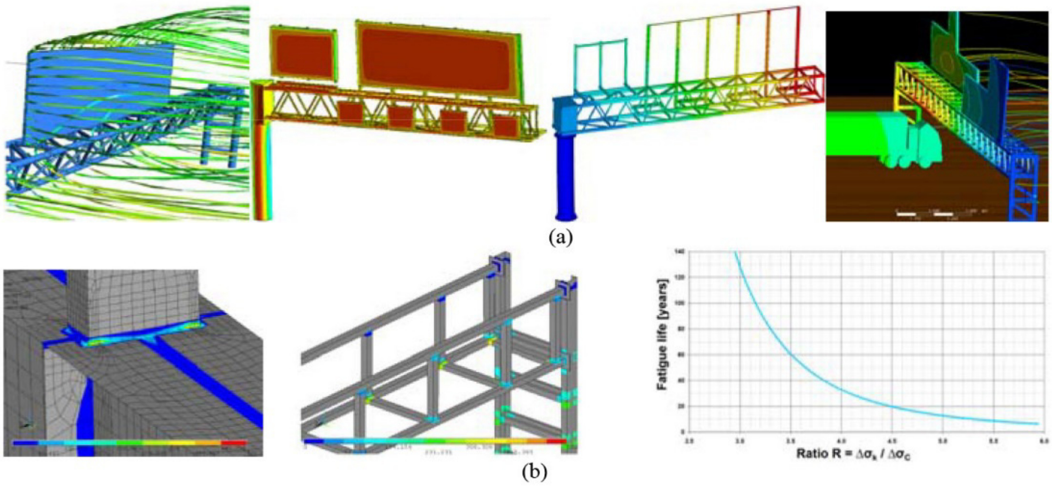
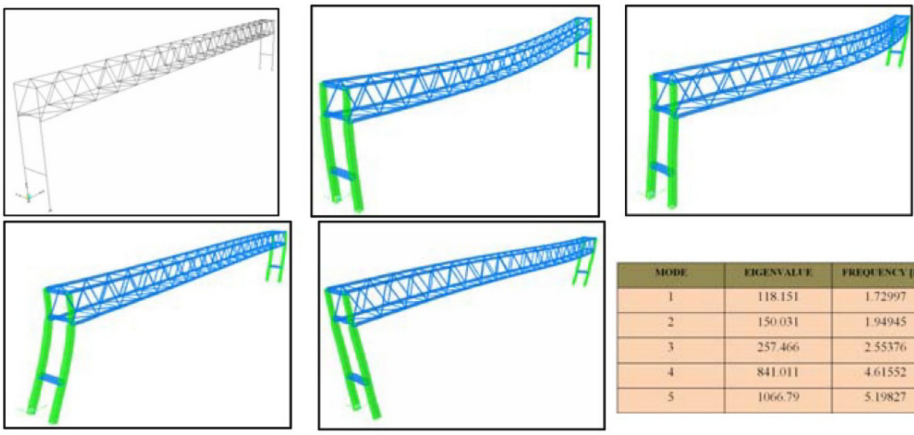


Fig. 3 (a) Gantry structures in virtual wind tunnel (environmental and vehicle buffeting); (b) Contour of fatigue life for critical gantry joints and automated fatigue life assessment graph.

4.2. Exact damped spectral-eigen analysis

While it is possible to find the basic dynamical behaviour of a large road structural system in the time domain using the conventional un-damped FE analyses, the accuracy of results would be inadequate when the effect of damping terms (viscous, aero-elastic…) on frequencies cannot be neglected. By using the frequency domain spectral element method, not only can the solution procedure take advantage of the exact shape functions (very few number of elements), but the natural features of the damping formulation in the frequency domain add considerable efficiency to the solution. Figure 4 shows a three dimensional spectral element model of a 46m span portal gantry. The mass and rotary inertia properties of the traffic signal boxes and signs have been created at their mass geometric centre and link to the model using rigid constrain equations. Figure 4 also shows the lists the first 5th natural frequencies and the first 4th natural mode shapes for the portal gantry structure. The material card is made up of isotropic material properties with fractional derivatives modulus (Horr et al. 1996) to take into account the damping effects (aero-elastic, joint friction, intrinsic material damping…). The linear mode superposition technique can be used as a final step of the analysis where by treating each mode as a single degree of freedom system, total dynamic response can be calculated directly by superposition of natural modes.



MODE	EIGENVALUE	FREQUENCY [Hz]
1	118.151	1.72997
2	150.031	1.94945
3	257.466	2.55376
4	841.011	4.61552
5	1066.79	5.19827

Fig. 4. Portal gantry line element model, its first forth mode shapes and natural frequency table.

4.3. Vehicle buffeting

The dynamic behaviour of large lattice structures under wind and buffeting loadings is causing fatigue assessment to be an important part of the design process. Fatigue induced crack propagation at joints is often one of the most critical aspects of design. Quantifying fatigue damage in the gantry structural members and joints due to dynamic effects such as wind gust and vehicle buffeting is complex. Accurate assessment of fatigue life as a result of the fatigue damage in accordance to the current codes of practice is also challenging task. The chain passage of high sided vehicles with their pressure cycles might trigger a resonance phenomenon (see figure 5) with flexural/torsional natural mode shape of the structure. If the portal gantry structure spans two carriageways and the lowest critical natural mode is a twisting mode, then the most critical passage scenario would be the passage of vehicles under the gantry in both carriageways simultaneously. However, if it spans two carriageways but the chosen lowest critical mode is a swaying mode, then the most critical passage scenario would be the passage of vehicles under the gantry on one carriageway, then on the other, then on the first again, etc.

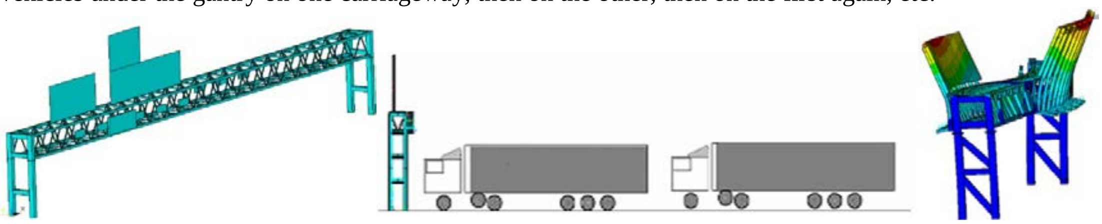


Fig. 5. Portal gantry model, vehicle tuned passage scenario and its resulting deflection.

To account for the vehicle buffeting effect in design of large highway structures, the moving mesh CFD and spectral-eigen results, presented in previous sections, can be used. The pressure time history of a single vehicle passage (from CFD moving mesh) can be used to construct a combined time history record using a range of possible time gaps between vehicles which generates the largest resonant effects.

5. Material process simulation - design for safer structures

The design of new crash-capable parts and the use of lightweight alloys (i.e., aluminium and magnesium alloys) for the lighter and more economical engineering systems have been presented in recent decades. The energy absorbing, crash suitability and fatigue issues are among the most important design concerns for the researchers and design engineers. The use of lightweight alloys for the design of these components has some serious implementations in terms of greener mobility, inertia reduction and passenger safety. The lower mass would improve the energy efficiency and modify the dynamic behaviour of the mechanical system while the lightweight components would have to be designed to protect the passenger against possible crash scenarios. In this section, following an in-depth study of material properties (for aluminium AA6005T6 alloy), absorption capacities, folding modes and geometric/production constraints; a frame work has been setup to develop a best simulation technique for extrusion process and also test an optimised aluminium extruded profile for best crash performance characteristics.

The alloy being studied here is an especial type of AA6005T6 alloy and the baseline test section (two-chamber profile) is extruded using conventional extrusion machine. A series of experimental programs has been planned and carried out to characterize the material properties (flow curves at different temperature…) for extrusion and crash simulation. A 300 mm long section of a lightweight section (crash-capable absorber part) has been modelled in order to keep the research work within the context of time and budget. A comprehensive study has been carried out to compare the crash and energy absorption performance of the existing hollow profiles with new alternative section shapes. In doing this the profile has been compared for its crash performance with a number of alternative new section designs. The extrusion process simulation geometry, mesh and strain results are shown in figure 6 where a FE mesh with small element size has been used to discretise the FE model. The dynamic simulations and virtual crash performance of vehicle components (crash-capable and energy absorbers parts) have been considered for the design of lightweight vehicles recently. The mathematical formulation of plasticity, energy absorption, large deformations, self-folding and contact have been developed by some authors and special attention has been devoted to the plastic deformation, rate dependency and tailored yield locus (von Mises, 1913 and Hill, 1948). There has also been quite an effort to develop an efficient mathematical and numerical technique for evolution of damage and failure during dynamical impacts.

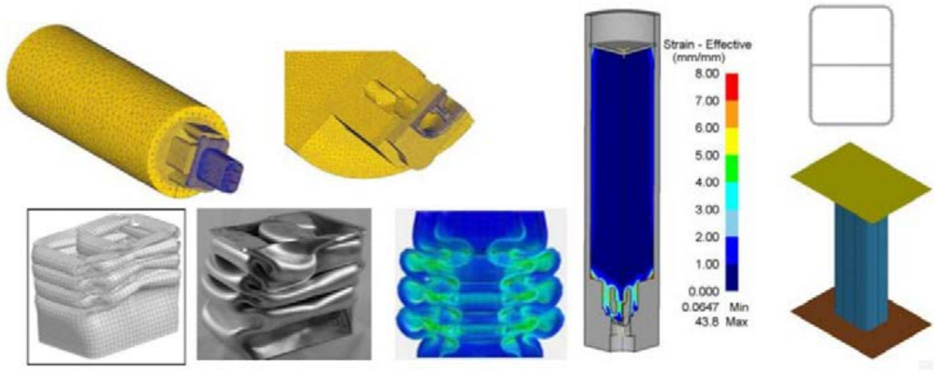


Fig. 6. FE mesh, effective strain contours, crash experimental test results along with simulated folding results.

6. Concluding remarks

A new numerical approach for the mathematical-numerical simulation of light weight hollow profiles for best energy absorption performance has been presented herein. The combination of forming process simulation and the sophisticated three dimensional dynamic, fatigue and explicit crash simulations (with advanced damage and failure modelling) have been used to study the crash-capable component. A series of experimental tests have also been carried out for selected profiles to verify the simulation results. The comparative analyses between the experimental and simulation results show that this upgraded numerical technique, with its combination of dynamics\fatigue\crash simulations, have generated reasonable accurate predictions for the dynamic, damage and failures in light weight roadside structural systems.

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