Development of Adaptive Meshing within LS-DYNA with Application to Impact Mechanics

Paul W. Bland[1]*, Sarin Tiranasawasdi[1]

[1] Department of Mechanical Engineering Simulation & Design,
The Sirindhorn International Thai-German Graduate School of Engineering,
King Mongkut's University of Technology North Bangkok (KMUTNB),
1518 Pracharaj 1 Road, Wongsawang, Bangsue, Bangkok 10800, Thailand.

*Corresponding Author: Tel: +66 (0) 2913 2500 ext. 2915, Fax: +66 (0) 2913 2500 ext. 2922,
E-mail: bland.p.mesd@tggs-bangkok.org

Abstract

Current research into theoretical and applied impact mechanics has required the development of adaptive meshing, centered upon the use of the full commercial version of the LS-DYNA solver. The work presented here is the first stage of developing adaptive meshing, specifically with application to the authors' current research into impact mechanics.

This paper focussed on the extreme impact simulation with high velocity/low mass (HV/LM) condition. The explicit LS-DYNA code was used to simulate the impact of a free flying projectile onto a flat plate target. Two approaches were used. The first used solid elements and the second used shell elements. Normal and Von-Mises stresses at mid-plane along the span on the top surface were observed over the contact duration time, specifically for the purpose of observing how the span wise plotted stresses evolve over time – referred to as stress profile evolution by the authors. In addition, total contact time, rebound velocity, and the maximum deflection of target were also observed.

In both cases, the models were compared to the authors' earlier work, which did not use adaptive meshing.

Solid element adaptive meshing produce numerical errors while remeshing. And requires further work to achieve basic functionality. Shell element adaptive meshing improved element quality in the impact zone by dividing elements into smaller size. The total contact time and the rebound velocity increased when projectile velocity increased, except damage case. The adaptive parameter should be carefully used to obtain the reasonable result.

***Keywords**:* impact regime, adaptive meshing, stress profile.

1. Introduction

Impact simulation has been used to predict the overall response of the structure to obtain impact history data such as deflection and stress-strain of the structure to help understanding the effect of impact in different regimes [1-4]. During impact simulation, when large deformation and subsequently large plastic strain were present, the elements in the mesh become progressively more and more distorted as the deformation increases. This may give severe numerical inaccuracies. The damage modelling added in the simulation by using erosion technique, deleting the elements when the plastic strain reached a critical value specified by the user, was used to avoid this problem. Although the damage modelling can solve this problem and made the simulation be more realistic, this method might lead to the new problem. It was the big gap between impact models after elements were deleted. This gap depended on the element size, so the element size significantly affected the numerical results. Therefore a sufficiently refined mesh was used. There are two main approach for improve meshing. First is fixed element meshing. This method refined mesh by reducing element size. Second is adaptive meshing that element are divided into smaller element or node moving when an error indicator shows.

Advantage of using adaptive meshing was to obtain more accuracy result because element qualities were better and used less computational time with more accurate result when compare with using refined mesh overall model. Disadvantage was after adaptive mesh, node and element number were changed and had to track node and element by manual. Adding damage model in the simulation by using deleting element, after nodes or elements were deleted, those node and element number were reused for adaptive meshing process. Hence, user had to check the result be careful after the extraction time history data.

There are few papers dealing with impact and adaptive meshing [5, 6]. Normally adaptive meshing was used in other application such as metal stamping and forging simulation. The adaptive method for shell elements is available in LS-DYNA and was originally intended for sheet metal stamping application.

The authors' pervious simulation work [1-4] of a free-flying projectile onto a flat plate showed regimes according to high (H) or low (L) projectile mass (M) and velocity (V), giving extreme conditions of LV/HM and HV/LM and transitions between. LV/HM showed Quasi-Static (QS) type behaviour with long contact times, continuous contact and global deflection approximated by the 1st mode response of the projectile and target as a lumped spring mass system. HV/LM showed continuous contact, short contact times and localised deflection. The transitions showed discontinuous contact or multiple contact and a delay in the formation of a global deflection. Simulation [1] has shown good general agreement with the characteristic behaviour of the regimes, and observed the development of the normal stress on the impacted surface varying in time and the span *x* direction. This type of stress appears to have a wave front simply because the stress amplitude changes over time and moves across the plate surface. This type of wave is referred to as a macro stress wave, to distinguish it from the micro scale of the fundamental stress waves. Simulations showed that the stress profile shape of extreme HV/LM regimes changed throughout the contact duration with three identifiable phases. Extreme LV/HM stress profiles also showed a changing shape, but only for the first 2-7% of the contact duration, and then switched to being a constant shape except for a scaled increased in amplitude. For impact conditions between the extremes, the switching time occurred later during contact, when moving from LV/HM to HV/LM [3]. A damage model was added specifically to allow for a more realistic behaviour for the case of penetration and perforation [2, 4].

The next step simulation for this paper is using the adaptive mesh to improve mesh quality around impact zone by repeated previous test cases and also check capability of adaptive mesh in LS-DYNA for this impact application.

2. Methodology

This paper has continued the work by looking in effect of adaptive meshing on the stress wave pattern or the macro stress profile and total contact time for extreme impact condition of HV/LM. The development of the macro stresses (normal stresses in span direction and Von-Mises stress) along the span on the impacted surface at mid-plane was observed.

LS-PrePost version 3.2 was used to prepare keyword input data and LS-DYNA version 971 was to simulate a 1 *g* free flying sphere projectile of diameter 6.35 *mm*, impacting on a flat aluminium plate target of thickness 2 *mm*, width 80 *mm*, span150 *mm*, rigidly clamped at both short sides. These test cases exactly repeated previous test cases, but with the only difference using adaptive meshing.

Projectile material was rigid steel with density of 7.85E3 kg/m^3, Young's Modulus of 200 *GPa*, and Poisson's ratio of 0.3. The aluminium plate was elastic-plastic strain hardening material with density of 2.77E3 kg/m^3, Young's Modulus of 71 *GPa*, Poisson's ratio of 0.33, yield strength of 280 *MPa*, and tangent modulus of 500 *MPa.* The strain rate was accounted for using the Cowper Symond model. The Cowper Symond parameters *C* and *P* for aluminium were 6500 and 4, respectively, which were found to be reasonable values from previous work [7, 8] and used in the authors' earlier work. The contact model used an element erosion approach selecting the LS-DYNA "eroding nodes to surface" algorithm for the contact condition between the projectile and target. The friction coefficient between projectile and plate was 0.61 for static and 0.47 for dynamic cases [9], which is coefficient of friction between aluminium and steel and also used in the authors' earlier work. An element was removed when the effective plastic strain in the element reached the critical value. This study used criteria failure strain (FS) as 0.5, which were reasonable values because elements were not too easily and hardly to remove as shown in the previous work [4].

A quarter symmetry structure was used in this simulation. The steel projectile was meshed with eight node solid element. The aluminium target was meshed with tetrahedron solid and quadratic shell element defining the *x* axis along the span, *y* axis through the thickness, and *z* axis across the plate width, with the origin at the centre of the plate on the top surface.

Adaptive mesh was used in the target. The 3D r-adaptive method was used for solid tetrahedral element. A completely new mesh were generated when minimum and maximum edge lengths of surface mesh surrounding the part were 0.2 and 0.8 *mm,* respectively, which was initialized from the old mesh using a least squares approximation. For shell element, all cases use h-adaptive method for 3D shells. Elements are divided into smaller elements when the adaptive error tolerance of total angle changes more than 10 degrees relative to the surrounding element. Element was divided into two for all sides from the original element size of the original element.

This work was the initial step to using adaptive mesh for HV/LM impact condition, so all simulation cases were designed for a low number of adaptive steps in order to easily tracking nodal and element time-history data.

Test cases are listed in table 1. For all cases, finer meshes as 4 elements of 0.5 *mm* element size were used for the area near the contact point and gradually coarser meshes incremental by 0.5 *mm* for the remaining region at the initial state. There was a special case set up, Test No. 5, to see effect of the adaptive error tolerance of the total angle changes parameter. Hence, Test No. 3 was repeated but using the adaptive error tolerance of total angle changes as 1 degree. This case would produce higher number of adaptive steps.

Table 1. Simulation test number and results.

Test No.	Element type of target	Impact energy (*J*)	Impact velocity (*m/s*)	Rebound velocity (*m/s*)	Contact Time (μs)
1	Solid	4.1	90.0	N/A	N/A
2	Shell	4.1	90.0	2.80	74.9
3		5.0	100.0	2.63	84.8
4		15.1	174.0	3.20	76.4
5		5.0	100.0	2.83	74.8

All results from simulation cases were normalised. All normal stress in x direction (Sx) were normalised with the maximum value of Von-Mises Stress (S_{eqv}). Time (T) was normalised with total contact time (T_C). The x direction was normalised with half of the span (L), and y direction normalized with plate thickness (h).

3. Results and discussion

3.1 Element type

Solid element adaptive meshing, Test No. 1, generated numerical errors. Simulation was terminated during program trying to remesh new element. That error was shown on the screen and in the messages file. In the LS-DYNA manual [10] referred that this option of 3D r-adaptive remeshing for solid tetrahedron elements remained under development. They might not sure of its reliability on complex model.

For shell element, the results did not have the same numerical error message as for solid elements. The maximum displacement was more than in the solid element, from the previous work, because shell element was more flexible. The rebound velocity was less than in solid element because flexible shell element can absorb more the kinematic energy of projectile than solid element.

3.2 Adaptivity

From all simulation results, adaptive mesh started and ended during the early impact event less than 10% of total contact time. Fig. 1(a)-(d) showed the final mesh around impact area of all simulation cases and number below picture was total number of elements. For No.2, adaptive mesh occurred once from 76 steps at 1.97E-6 *sec* or 2.6% of total contact time around the impact zone without deleted element. An adaptive mesh area is define to contain all elements that underwent adaptive meshing, and is quantified as a radius of a circle centred upon the impact contact point. The adaptive mesh area for case No. 2 was 1.5 *mm* as shown in Fig. 1(b).

For Test No. 3, adaptive mesh occurred once from 425 steps at 7.86E-7 *sec* or 0.9% of total contact time around the impact zone and element was deleted 1 element at impact point at 9.79E-7 *sec* or 1.2% of total contact time. The adaptive mesh area was 1.5 *mm* as shown in Fig. 1(c).

For Test No. 4 when increased impact energy, adaptive mesh occurred 7 steps from 383 steps at 1.77E-06 (2.3%), 1.98E-06 (2.6%) T, 2.17E-06 (2.8%), 2.99E-06 (3.9%), 5.78E-06 (7.6%), 5.98E-06 (7.8%), and 6.19E-06 (8.1%) *sec,* respectively, the number in bracket is the percentage of total contact time. Adaptive mesh area was 3 *mm* as shown in Fig. 1(d).

From Test No. 3 result, the special test, Test No.5, was setup to see effect of adaptivity parameter from changing the adaptive error tolerance of total angle changes from 10 to 1 degree. The result showed that the adaptive mesh occurring 18 steps of 375 steps without deleted element. Adaptivity process started from 1.91E-07 *sec* (0.3%) to 7.04E-05 *sec* (94.1%) when total contact time was 7.48 E-05 *sec.* Fig. 1(e) showed the final state of adaptive mesh having the largest adaptive mesh area and element were divided into smaller size than other cases. Fig. 2 showed the adaptive mesh processing during the impact events of Test No. 5. The more deflection of target occurred, the more elements divided. There was no severe distorted element at impact area or adaptive mesh area.

3.3 Total contact time and rebound velocity

The total contact time increased by increasing projectile velocity, except Test No. 2 as shown in Table. 1. The contact time of Test No. 2 was longest because the element at contact point was deleted, so penetration occurred and made target softer and more flexible.

The rebound velocity increased by increasing projectile velocity.

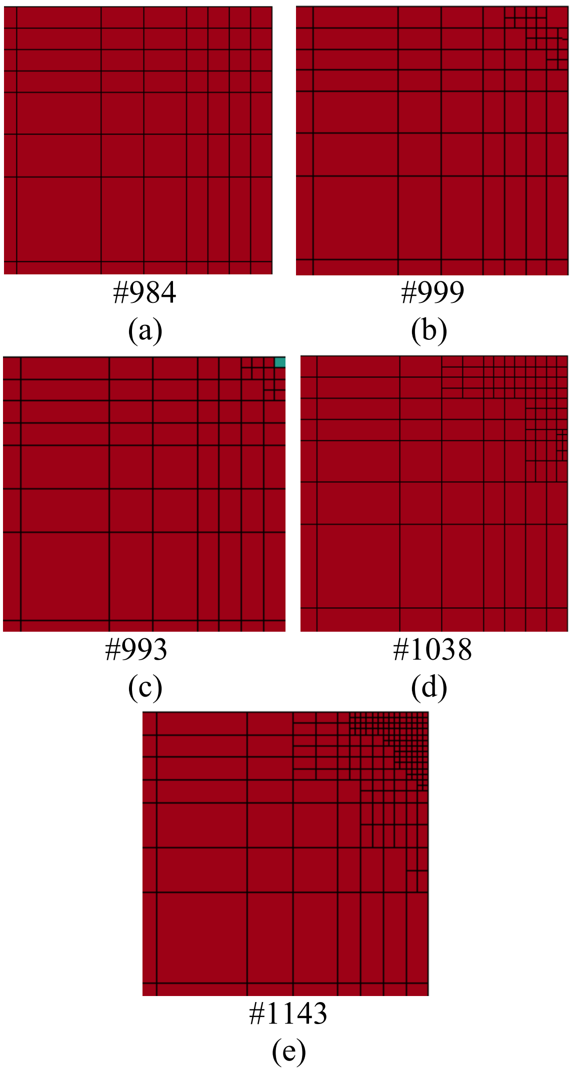


Fig. 1 Compare the original mesh (a); with the final mesh of Test No. 2 (b), Test No. 3 (c), Test No. 4 (d), and Test No. 5 (e).

3.4 Stress profile pattern

The stress profile of normalized stress *Sx* of HV/LM condition still show the existing of changing profile into 3 distinct phases but it was not clearly show Phase 1. That was because adaptivity process started during the stress profile performed Phase 1, which show up to the first 5% of total contact time [3], and the wave peak or wave front was in the adaptive mesh area.

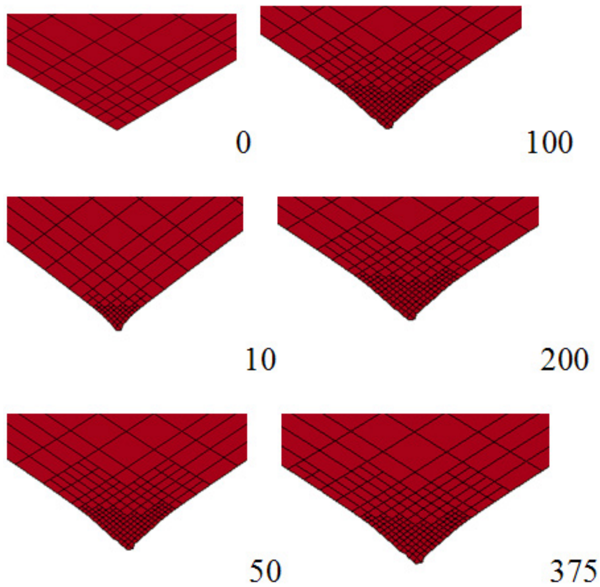
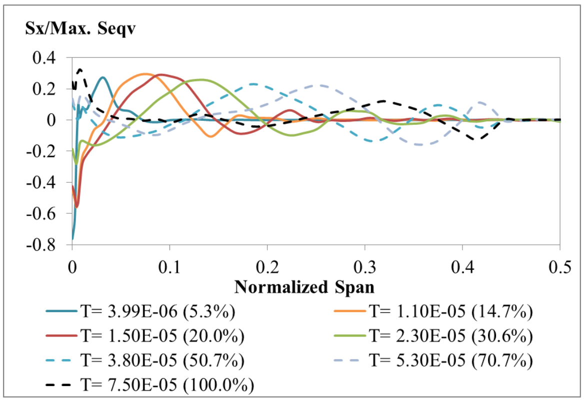


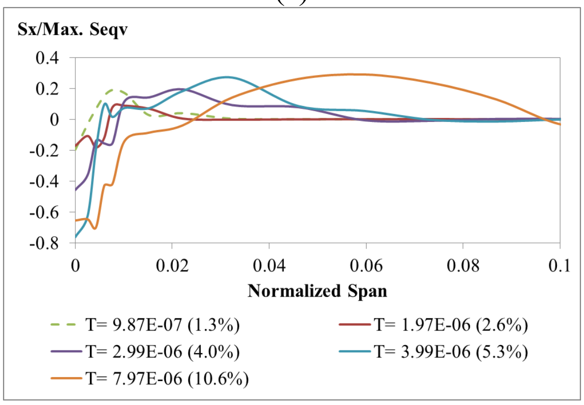
Fig. 2. Adaptive meshing process of Test No.5, from step no. 0 (the original mesh), 10, 50, 100, 200, and 375 (the end of contact time)

The stress profile of normal stress *Sx* was not clearly shown smooth profile line after additive meshing was occurred. The example is Test No.2 as shown in Fig. 3, the stresses are normalised against the maximum Von-Mises stress observed during impact, and are plotted against normalised span dimensions with the centre span and contact location being at zero, and the plate edge at 0.5. *T* is time in *sec* and the number in bracket is the percentage of the total contact time. Fig. 3(a) showed the stress profile of *Sx* during the total contact over a half span. The dash lines presented stress profile after developing of the maximum deflection. This stress profile clearly presented Phases 2 and 3, but not clear for Phase 1 as clearly shown in the previous work [3] in Fig. 4. Fig. 3(b) was zoomed in the Fig. 3(a) to see Phase 1. At that time, the stress profile should show Phases 1. In Fig. 3(b), the dash line presented the stress profile before adaptive mesh. This line still smooth as usual. After adaptive meshing time, *T*=1.97E-6 (2.6%) *sec,* the stress profile was presented by the solid line. The stress pattern was not smooth around the adaptive mesh area; normalized span is 0-0.01.

The stress profile of Von-Mises stress showed all phase clearly as shown in Fig. 5(a). In Fig. 5(b), the dash line presented the stress profile before adaptive mesh and this line was smooth. After adaptive meshing, the solid lines presented the stress profile and they also were not smooth around the adaptive mesh area; normalized span is 0-0.01, when compared with the previous work [3] in Fig. 6.



(a)



(b)

Fig. 3 (a) Stress profile of normalized stress *Sx* in span direction (*x* direction) at the mid line of the plate along span, Test No.2. (b) show the stress profile during first 10% of the contact time.

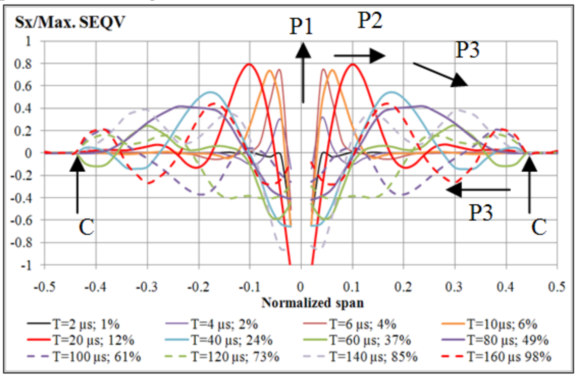
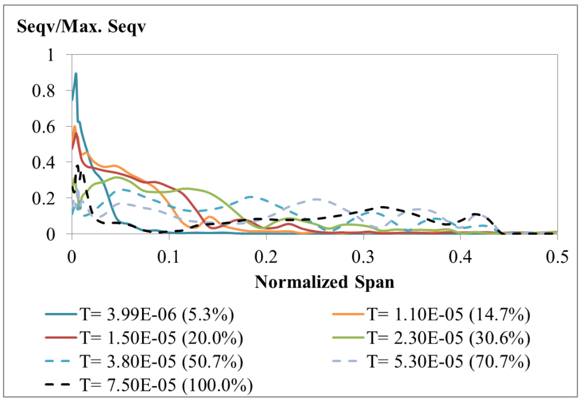


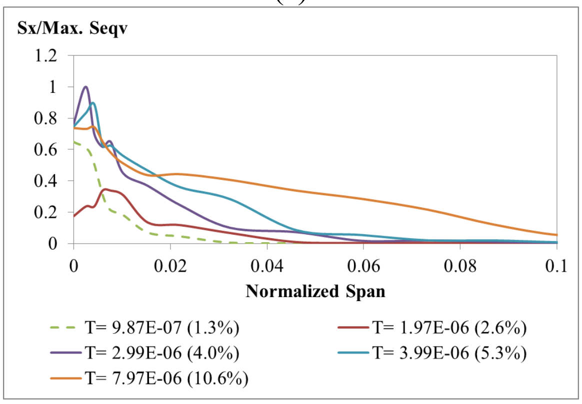
Fig. 4 Stress profile of normalized stress *Sx* at the mid line of the plate along span for HV/LM impact condition [3]

4. Conclusion

Adaptive mesh in solid element for impact simulation of HV/LM condition got error while it worked very well in shell element for all cases, adaptive mesh with and without deleted element. The normalized stress profile pattern of *Sx* did not show clearly enough when adaptive mesh was occurred while the normalized stress profile pattern of *Seqv* showed clearly enough.



(a)



(b)

Fig. 5 (a) Stress profile of normalized stress *Seqv*. in span direction at the mid line of the plate along span, Test No.2. (b) show the stress profile during first 10% of the contact time.

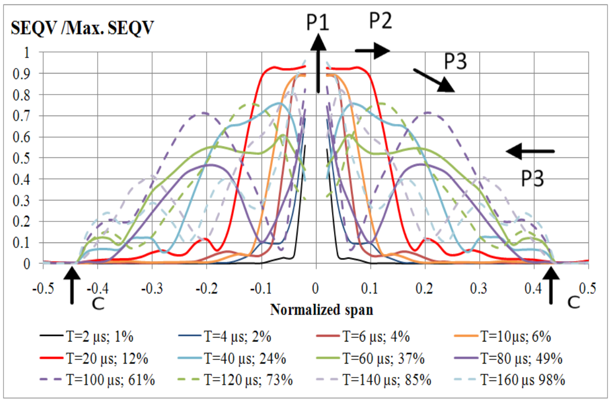


Fig. 6 Stress profile of normalized stress *Seqv* at the mid line of the plate along span for HV/LM impact condition [3]

Adaptive meshing can improve the result to obtain more accuracy data because element quality was better if compare with the original model, and used less computational time with more accurate result if compare with the refined mesh model. .One disadvantage with adaptive meshing approach is the extraction of history data such as displacements and stresses from node and element after adaptive meshing because node of none and element were changed. Especially in case of element and node were deleted and mesh was adapted, the deleted element or node number would be reused in adaptive process.

Further work is to study more adaptive parameter for shell element to looking for the suitable value for the application and had to develop the script that has robust for impact simulation in order to extract time history data of nodes and elements after for adaptive meshing.

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