Global and Local Coupling Analysis for Small Components in Drop Simulation

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ABSTRACT

The failure induced in radio/phone drop often associate with the damage of inside small components or its tiny substructures. The difficulty to detect the failure in drop simulation is: i) the right drop-induced shock at the components must come from the simulation at whole-phone model; ii) the required output at the small components needs very fine local mesh, which causes unbearable CPU cost and make the simulation impossible. Mass-scaling technique is unsuitable for the case. A global-and-local coupling method is presented in this paper to solve the problem. The method is demonstrated by an example of a connector (global model in coarse mesh) to search stresses of its solder joints (local model). The displacement and stresses calculated by the method are correlated to the results from a finely meshed model. The correlation verifies good agreement of calculated displacement in the two models, and small difference of stress prediction. The source of the error and possible improvement are analyzed in the paper.

INTRODUCTION

The drop-induced failure of radio/phone often associate with the damages of small components and its tiny substructures inside the radio/phone, for example, disconnection of connector and break of components' solder joints. The drop behaviors of these components must be checked in whole-phone drop simulation, which induces right shocking loads from the impact at housings to the inside components. The disconnection and the break of concerned components can be detected by relative displacements and stresses from output data of drop simulation.

A special difficulty of above analysis in whole-phone drop simulation is that the tiny inside substructures, where output is expected, lead extreme fine meshes. The step time of explicit FE analysis used in drop simulation is controlled by the minimum element size. The fine mesh only for the particularly concerned parts causes too much CPU cost in whole-phone drop simulation. A drop simulation usually is controlled at 0.5 – 1.5 CPU hours for one millisecond of simulation time. Typically, a case of phone drop needs about 3 - 8 hours computing time. The locally, finely meshed parts will prolong the running time to over 100 hours. Mass-scaling technique is not suitable for the cases. The vastly increased mass at the parts to enlarge step time will dramatically change their drop behavior.

Global-and-local method can overcome the difficulty. The method, coupling global simulation (whole radio/phone level drop simulation) and local analysis (only tiny substructures themselves), is a suitable solution to analyze drop performance of the small parts.

The study in this paper takes a connector as an example to demonstrate the method. The demonstration is aimed at accuracy of displacements and stresses predicted by use of the method. The displacement accuracy is crucial to predict disconnection, and the stresses are the key to detect breaking of component attachment. Here, a connector model plays the role of global model, and its sold joints are considered as local substructure. Other parts are ignored for correlation. The reason of this simplification is that a finely meshed model at whole-phone level is impossible to get simulation results as baseline.

In the global model, a coarse mesh is adopted, and lead – solder attachment is replaced by equivalent spring support. The purpose of the global analysis is to introduce right impact load from global drop behavior to the local model. A local static analysis is needed before the global simulation to determine stiffness of the spring support. Another local analysis of joint is conducted after the global simulation to calculate detailed stresses. Besides, an additional global model in fine mesh is run to provide baseline for correlation.

An analysis with global-and-local coupling method is fulfilled at three steps:
Step 1: A local analysis with fine mesh to determine equivalent stiffness of spring support
A given load, normal and shear forces respectively, is subjected to the connector. The calculated displacement of the connector's leads is used to determine the support stiffness. This static analysis, other than a simple estimation from material properties, is necessary to get accurate support stiffness. The following results verified the quite difference of FE model and simplified estimation, because of solder's non-uniform deformation and lead's bending.

Step 2: A coarsely meshed model running in global analysis:
The whole connector model in coarse mesh is subjected to shock. The sold-joint attachment of the connector to PC board is replaced by spring support with the stiffness coming from the static analysis at Step 1.

Step 3: To determine stresses of joint in finely meshed local model
The analysis of solder joint stresses comes back to a local model. The model includes a lead and a solder joint only, with fine mesh. A displacement output from global simulation at Step 2 is input to the model. The detailed stresses of solder joint are obtained at this step.

Without losing its generality, only segment of the connector, with sixteen pairs of leads and solder joints, is modeled for efficiency. Assumed shocks is given by a pulse, normal and shear forces at 0.24 ms, which is subjected to the connector. Two global models of the connector are set up in the same geometry and load condition. One is finely meshed. The dynamic response of the model is used as baseline. Another model in coarse mesh is used to perform the global-and-local coupling analysis. The results from the model will be correlated to the baseline to check accuracy of the suggested method. The correlation is focused on the displacements and stresses of solder joints.

MODEL SETUP

Fine meshing of a socket segment with eight lead – solder pairs at each side is created, see Figure 1. The element size is about 0.1-0.2 mm. The model is described in Table 1. The model has total 8362 elements. The baseline for correlation is obtained at the model. And it's also used into static analysis to determine stiffness of support springs. Another model in coarse mesh with spring support is illustrated in Figure 2, and explained in Table 2. The model has 489 elements, about 6% of the finely meshed model. The leads and solder joints are replaced by springs.

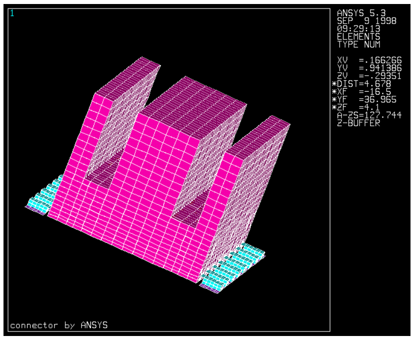


Figure 1. The model in fine mesh

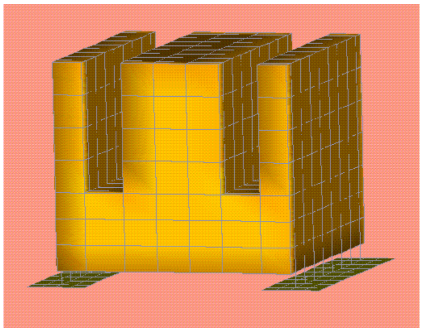


Figure 2. The model in coarse mesh

Table 1: The fine meshing model

Part	type of element	number of element	Density (kg/mm**3)	E (Gpa)	μ	Thickness (mm)
Solder	hexahedron	320	8.8e-6	13.0	0.35	
Socket	hexahedron	6992	1.2e-6	2.3	0.4	
	Pentahedron	384				
Lead	quadrate	256	8.7e-6	124.0	0.33	0.2
Board	quadrate	410	1.9e-6	14.0	0.2	1.0
Total:		8362				

Table 2: The coarse meshing model with spring support

Part	type of element	# of element	Density (kg/mm**3)	E (Gpa)	μ	Thickness (mm)
Socket	hexahedron	369	1.2e-6	2.3	0.4	
Board	quadrate	72	1.9e-6	14.0	0.2	1.0
Support	spring	16*3		stiffness from static analysis		
Total:		489 (5.8% of the model in fine mesh)				

ANALYSIS AND RESULTS

1. The Baseline

The finely meshed model subjected to a semi-sine pulse of assumed impact force

The model in fine meshing (8362 elements) is subjected to a time dependent normal/shear force of semi-sine wave during 0.24 ms. The loading curve is given in Figure 3. The deformation modes can be checked in animation data. The result data of transient analysis by LS-DYNA are expressed in time history curves. The z-displacement at top connector and stresses of solder joints are picked up in the case under normal force. The y- and z-displacements and stresses of solders are quoted in the case under shear load. Two loading conditions are considered in the correlation – tension and shear at the connector. This arrangement is to correlate the results under these two basic loading conditions. The general cases can be considered as the combination of the basic cases. The result data at the model are used as baseline to correlate the analysis in global-and-local coupling method.

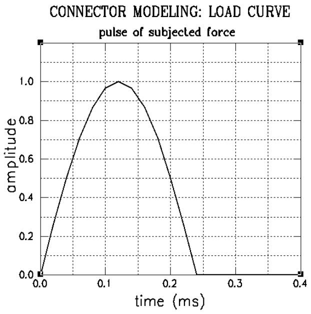


Figure 3. Loading curve

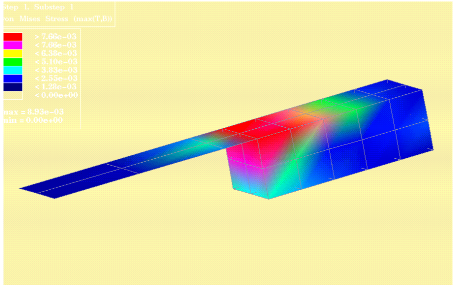


Figure 4. Stress distribution at a solder joint

2. Static analysis with Ansys (Step 1 of the coupling method)

1)An uniform tension of 2.5e-4 Gpa is subjected to surface of socket cavities. The acting area is about 5.0 * 0.8 = 4.0 mm*mm (one side). The total tension resultant is 2 N. The displacements picked at leads are listed in Table 3. There are eight leads and three nodes at every lead. The result comes from static analysis of ANSYS.

The deformation includes solder tension and lead bending, which can be observed in deformation mode. The average z-displacement is 1.26. The tension stiffness is calculated as

2.5e-4 * 4.0 / 1.26e-4 / 8 = 0.99 kN/mm

Table 3: Displacement under normal pressure (in 0.0001 mm):

	Node 1			Node 2			Node 3		
	X-dis.	Y-dis.	Z-dis.	X-dis.	Y-dis.	Z-dis.	X-dis.	Y-dis.	Z-dis.
Lead 1	0.17	0.19	1.30	0.13	0.18	1.28	0.085	0.18	1.24
Lead 2	0.17	0.13	1.26	0.13	0.13	1.26	0.098	0.12	1.24
Lead 3	0.15	0.083	1.26	0.13	0.077	1.27	0.11	0.071	1.26
Lead 4	0.13	0.031	1.26	0.13	0.026	1.27	0.12	0.019	1.26
Lead 5	0.12	0.019	1.26	0.13	0.026	1.27	0.13	0.032	1.26
Lead 6	0.11	0.071	1.26	0.13	0.077	1.27	0.15	0.083	1.26
Lead 7	0.098	0.12	1.24	0.13	0.13	1.26	0.17	0.13	1.26
Lead 8	0.086	0.18	1.24	0.13	0.18	1.28	0.17	0.19	1.30

As a comparison, the following data give solder deformation and lead bending. The number in the first column is z-displacement measured at the solder root. The second is z-displacement at lead root. The difference between them represents lead bending.

Table 4: Z-displacement of lead and solder joint in 0.0001 mm:

	Node 1		Node 2		Node 3	
	Solder	Lead	Solder	Lead	Solder	Lead
Lead 1	0.748	1.30	0.739	1.28	0.689	1.24
Lead 2	0.719	1.26	0.732	1.26	0.704	1.24
Lead 3	0.720	1.26	0.734	1.27	0.713	1.26
Lead 4	0.721	1.26	0.740	1.27	0.719	1.26
Lead 5	0.719	1.26	0.740	1.27	0.721	1.26
Lead 6	0.713	1.26	0.734	1.27	0.720	1.26
Lead 7	0.704	1.24	0.732	1.26	0.719	1.26
Lead 8	0.689	1.24	0.739	1.28	0.748	1.30

The average displacement due to solder deformation is 0.723, 57% of the total deflection. The rest of 0.537 comes from lead bending. The stiffness of the joint is

2.5e-4 * 4.0 / 0.723 e-4 / 8 = 1.73 kN/mm

The value is quite different from the stiffness simply calculated from material property and geometry. The calculated stiffness in this manner is

13.0 * 0.583 * 0.27 / 0.19 = 0.8 kN/mm

The difference is caused by bending of leads and non-uniform deformation of the solder joints (the stress distribution at solder is shown in Figure 4), which is ignored in above simplified calculation. The comparison is to emphasize the necessity of the static analysis to determine equivalent stiffness of the support.

2) Equivalent stiffness in Y- and Z-direction:
The stiffness is calculated from the same model, but the distributed loads are changed to Y-direction shear. The Y-displacement is picked up for determination of Y-direction stiffness.

Table 5: Y-displacement in 0.0001 mm at y-shear force:

	Node 1	Node 2	Node 3
Lead 1	2.11	2.10	2.10
Lead 2	2.21	2.21	2.27
Lead 3	2.27	2.27	2.27
Lead 4	2.30	2.30	2.30
Lead 5	2.30	2.30	2.30
Lead 6	2.27	2.27	2.27
Lead 7	2.27	2.21	2.21
Lead 8	2.10	2.10	2.11

The mean value 2.22 is taken from the list. The equivalent stiffness in Y-direction is

1.0e-3 / 2.22e-4 / 8 = 0.563 kN/mm

The X-displacement is picked up under X-shear force, see Table 6.

Table 6: X-displacement in 0.0001 mm:

	Node 1	Node 2	Node 3
Lead 1	0.390	0.342	0.297
Lead 2	0.373	0.344	0.317
Lead 3	0.363	0.348	0.335
Lead 4	0.355	0.349	0.346
Lead 5	0.346	0.349	0.355
Lead 6	0.335	0.348	0.363
Lead 7	0.317	0.344	0.373
Lead 8	0.297	0.342	0.390

0.347 is adopted as mean X-displacement. The equivalent X-direction stiffness is

1.0e-3 / 0.347e-4 / 8 = 3.60 kN/mm

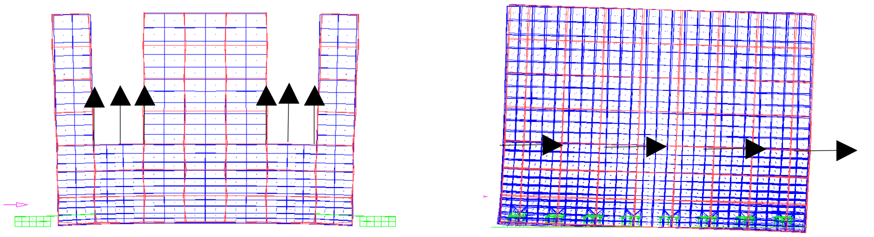
The stiffness in three directions is acquired to define spring support in global model.

3. Dynamic analysis at simplified model (Step 2 of coupling method)
The simulation in this step should be conducted under drop condition. In this study, the impact load is given as the same as the base case for correlation purpose.

1) Normal loading case:
The coarsely meshed model is subjected to the semi-sine loading, the same as the baseline. The results are obtained from LS-DYNA solver. The displacement correlation is carried out at first, because the disconnection prediction in drop simulation entirely depends on the accuracy of the calculated displacement. The deformed configurations of the two models, in fine mesh and coarse mesh, are compared in Figure 5. The pictures are quoted at 1.5 ms of

deformation history, the moment undergoing maximum deformation. The subjected tension causes a global moving up. The center goes up a little more. Two sidepieces bend outward due to restriction of solder joints. The picture shows very good agreement of deformation mode from the different models. Figure 6 gives displacement comparison of time history curves. The displacements are picked up at the top of the connector. The dashed lines are the result of coarsely meshed model correlated to the baselines plotted as solid lines in the same color.

Another group of displacements is picked up at spring end. The displacements expressed in time-dependent dynamic response will be used in following analysis as given displacements input to calculate stresses of solder joints.



Deformation at 1.5 ms under normal tension (front view)

Deformation at 1.0 ms under shear loading (side view)

Figure 5. Correlation of deformation (blue - baseline; red - coarse meshed model)

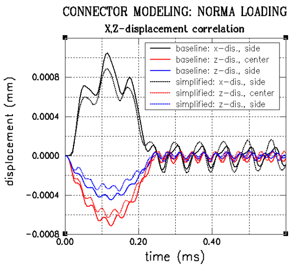
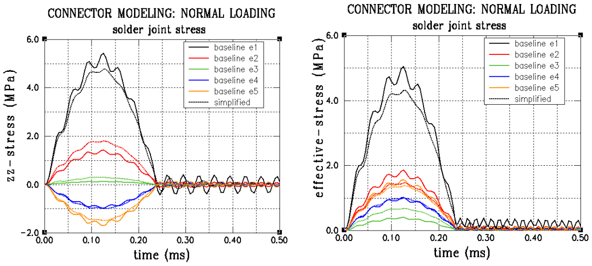


Figure 6. Displacement correlation Under normal loading



zz-stress

effective stress

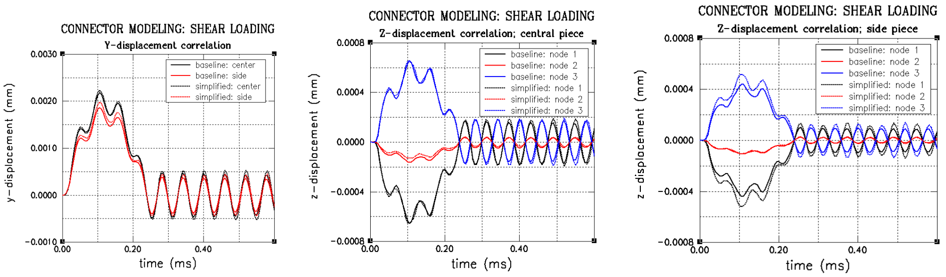
Figure 7. Stress correlation under normal tension

2) Sear Loading case:

The same simulation as the normal loading case, but distributed shears subjected to the connector, is conducted for correlation. The connector waves with a little rotation. The deformation can be checked on the right hand of Figure 5. The picture is quoted from animation at 1.0 ms. The baseline (blue) and the data from coarsely meshed model (red) coincide very well. Figure 8 shows correlation of time history curves. The locations to pick up the data are chosen at central piece of the connector and its sidepiece. As the normal loading case, the displacements at spring end are picked up for following stress analysis of solder joint.

4. Stress prediction of solder joints (Step 3 of coupling method)

In this step, only a lead and a solder joint is modeled under the given displacement input. The model used is the same as Figure 3. The time-dependent displacements from Step 2 are acted on the lead.

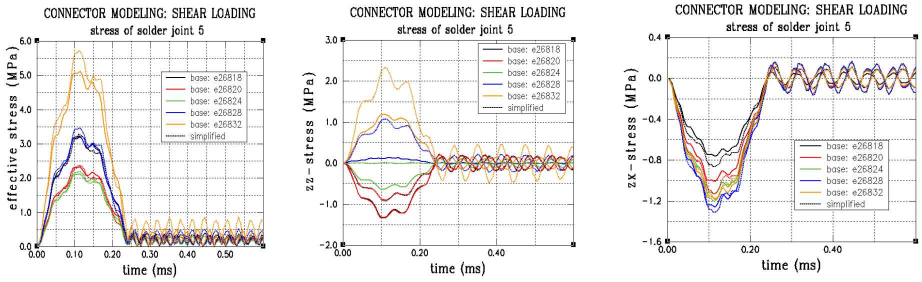


y-displacement z-disp. of central piece z-disp of sidepiece

Figure 8. Displacement correlation at shear loading

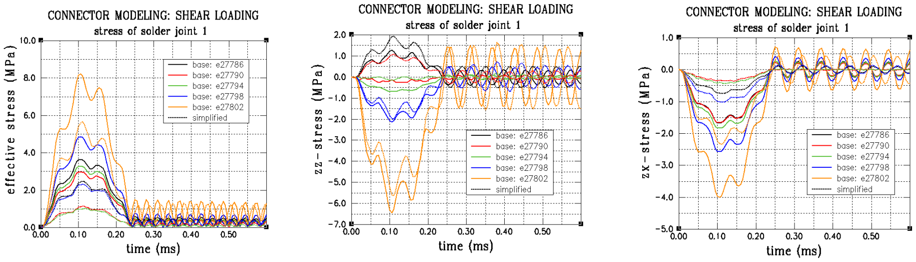
In normal loading case, the deformation of solders is uniform. A solder is chosen to be analyzed. The stress correlation is demonstrated in Figure 7. The dominant stress component is zz-stress. The curves of zz-stress and effective stress (von-misses stress) are plotted in the figure. In the effective stress plot, the timing of pulse is correlated very well. The maximum value from coarsely meshed model is about 14% less than the baseline.

In shear loading case, the deformation of all solders is diverse. The maximum deformation occurs at the end solder due to rotation under the shear load. A solder at central connector and a solder at the end are chosen to validate their stresses in Figure 9 and Figure 10. The dominant stress is still zz-component, but shear stress has bigger contribution to the effective stress than that under normal load. At the central solder, the error of the maximum effective stress in the simplified model is about 14 % higher than the baseline. The stress at end solder is about 28 % less than the baseline. The error mainly is caused by the gap of shear stresses calculated in the different models, which can be checked in the right plot of Figure 10.



effective stress zz-stress zx-shear stress

Figure 9. The stress at central solder joint under shear loading



effective stress zz-stress zx-shear stress

Figure 10. The stress of edge solder joint under shear

CONCLUSION

1. The global-and-local coupling method is a solution to realize the detailed analysis of small components in phone drop simulation. The idea is based on the fact that the global dynamic response affects the local behavior, but the local behavior has little contribution to change the global performance. The global analysis provides loading condition to local analysis. The local analysis at fine meshing will not loose its accuracy using the loads obtained from the global simulation at coarsely meshed model. In the simplified model, solder joint is replaced by springs, which eliminates the unbearable CUP cost by the tiny, local substructures. In phone drop simulation, the coarsely meshed model of the connector with spring support should be assembled into a whole-phone model, and Step 2 should be conducted in drop condition.

2. The correlation verifies accuracy of the method. The correlation demonstrates excellent agreement of displacements in the two models, which will lead reliable disconnection prediction in the simplified model. The margin of stress prediction is about 15 % in most cases.

3. The stress error in the correlation basically results from shear stress. In the simplified model, equivalent spring replaces the solder joint attachment. The static analysis defines the stiffness in three axial directions of the springs , but the shear stiffness existing in the solder joint attachment can’t be remained in the spring model. It causes error of shear stress calculation. The error will be increases in the cases where shear stresses become significant. In this study, only eight-lead segment of the connector is modeled for efficiency. The actual connector has 35 leads, five times longer than the model. We can approach the conclusion that the rotation under the shear loading will much reduce in the full model with 35-lead support, especially, the error at end solder induced by the ‘edge effect’ will significantly reduce. The real stress distribution tends to uniform than that at end solders, and closes to the distribution at central solder, shown in Figure 9.

4. The drop performance of connector must be checked in whole-phone drop simulation / test. No conclusion can be made for an individual component. The reason is that the shock to the component depends on the whole phone structure, and the interaction of the inside parts. The shock initiated at impact location will spread to whole housing, then propagate to board and the attached components through connecting paths (screws, snap-in and contact among parts). This complex process must be investigated in whole-phone level simulation / test to determine the shock subjected to an individual component. The study presented in this paper is to search a method that can overcome the restriction subjected to impact analysis by small substructure, and realize the component level analysis in whole-phone drop condition. The drop simulation for whole-phone model with the global-and-local method will be conducted soon in the projects to support design and manufacture of new products.

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