Engineering Analysis with Boundary Elements 36 (2012) 1296–1300

Contents lists available at SciVerse ScienceDirect

Engineering Analysis with Boundary Elements

journal homepage: www.elsevier.com/locate/enganabound

Stress analysis of a front bumper fascia using the boundary element method

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ARTICLE INFO

Article history:
Received 13 June 2011
Accepted 3 February 2012
Available online 14 March 2012

Keywords:
Boundary element method
Numerical analysis
Front bumper fascia
Automotive components
Stress analysis

ABSTRACT

Stress concentration is one of the most common problems related to automotive components and numerical analysis can be of great interest to deal with such problems. The boundary element method (BEM) is a technique which can be used in stress analysis and it is specifically applied to the design of a car component here. This work presents the efficacy of the application of a procedure based on BEM sub-model for stress analysis in a proposed design change of a front bumper fascia. The results confirm the consistency of the proposed procedure compared to the finite element method (FEM), a consolidated method for stress analysis in the automotive industry.

1. Introduction

The boundary element method (BEM) is a well-known numerical technique for solving a wide range of problems in applied science and engineering [1]. One of the advantages of this method is that only the boundary has to be discretized in order to compute the solution for the whole domain. The elements, generated by the discretization process, are arranged on the surface of the material and represent the boundary conditions.

Betti [2] was the first author to study the theory of elasticity using integral equations relating the strength and displacements applied on the surface boundaries. Fredholm [3] used integral equations to formulate the problems of boundary value and demonstrated the existence of a solution using a specific numerical method ("Operator Theory") applied to a problem in which continuous partial derivatives are allowed. Rizzo [4] obtained a boundary integral equation for stresses within an elastic, linear and isotropic body. Jaswon et al. [5] developed one of the first formulations of BEM to bend plates when the technique was known as the boundary integral equations method. Later, Cruse [6] developed a numerical solution for three-dimensional problems involving unknown surface tractions and displacements through a fully automated process to investigate a significant problem with stress singularities. Since then a large number of works have been published by several other authors popularizing the use of this method [7–11]. In general, they are related to specific standard samples or plates in order to predict crack geometry.

Currently the most commonly applied method in the automotive industry for stress analysis is the finite element method – FEM [12,13]. FEM is based on a finite elements definition (mesh discretization of a continuous domain inside a set of discrete sub-domains) which originally arises from the structural analysis of the component to be modeled. Initially the method was used in the aeronautics industry and nowadays the method is still used in this area, however, much enhanced by the advances in computing [14]. It has also been used in the first steps of a process design to reduce product development timing [15]. The main difference between BEM and FEM is the fact that in the former only the boundary of the domain needs to be discretized whereas the latter requires the entire volume discretization of the component analyzed. This can be considered an advantage for stress analysis due to the local remeshing facilities. For this reason BEM is capable of representing regions with small details without complex meshing and it also provides good prediction for the stress field.

BEM is a consolidated method used in engineering and other related areas [16–18]. Although the use of BEM is increasing in the car industry, mainly in the areas of acoustics and vibration [19], there have been few works using BEM for stress analysis in automotive components.

This work presents a procedure for applying BEM for stress analysis in automotive components based on the sub-model technique [20]. It comprises the extraction (or selection) of small surface areas of a steel bumper fascia and application of traction to obtain specific values of stresses in the areas selected. The areas can be identified based on historical data of a failure which occurred in similar components or through stress distribution predicted by FEM. A number of techniques can be put together in an original way to analyze a complex case study, related to the possible changes during the product development phase, to support decision making in the automotive industry.

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doi:10.1016/j.enganabound.2012.02.008

It should be understood that a surface with a complex geometry is one in which there are structural differences that cannot be generated by traditional manufacturing processes (Müller et al. [21]) such as a stamping production line with less than five steps for which simple geometry cases (Herrin et al. [22]) can be applied. Bumpers, for instance, can be considered components with a complex geometry. Currently they are made from a metallic material for application in light trucks. Although metallic bumpers have similar shapes to plastic covers (which only have an esthetic function), they are considered structural as well as esthetic components when applied to light trucks.

In this work, a bumper fascia surface with complex geometry was considered. The sub-model technique has been used to reduce the size of the original model and thus the computational effort, enabling the use of BEM without needing a dedicated workstation. The use of the proposed method in the automotive industry can provide quick results of easy manipulation and interpretation for all product engineers. It can also provide technical support for styling change proposals based on preliminary surface suggestions.

Section 2 highlights some aspects of the BEM for stress analysis and shows the materials and methods used for the numerical analysis. Results and discussion are presented in Section 3 and conclusions in Section 4.

2. Material and methods

The basic problem to be solved using BEM comprises the prediction of stress fields in a component which is subjected to loads on its surface. The numerical procedure requires some preliminary definitions such as the number of elements and nodes, load direction and position, clamps and material properties. The method can be applied to any characteristic of the material and thickness with no restrictions on geometry.

BEM was first used by Brebbia and Dominguez [23] which emphasized the simplicity of boundary methods for potential problems in engineering. The complete foundation of BEM can be found in Rizzo and Shippy [24]. The BEM discretization process deals with equations involving only boundary integrals which require less computation. Moreover, the method can be used for three dimensional problems which require mesh modification or refinement. As in most numerical methods that involve domain discretization, the refinement process comprises the reduction in size of each element in order to improve the accuracy of the results. On the other hand, excessive refinement can bring the numerical procedure to a standstill due to the size of the generated file. The simplicity of mesh generation and refinement using BEM can reduce the computational time in problems associated with prediction of stress concentration.

The type of steel currently in use in the automotive industry was selected for use in a front bumper fascia for a light truck. More specifically, this is cold rolled steel SAE J1392 grade 035 with thickness 1.5 mm, yield strength range from 250 to 350 MPa, tensile strength 350 MPa minimum and elongation 0.25 minimum. Fig. 1(a) shows the front bumper fascia mesh, the proposed direction and location of the static load (F) applied (red arrow) and the analyzed zone is circled. Clamping loads were applied in the same position as the component attachment points in the vehicle.

In order to evaluate the performance of BEM in case examined here a design change was proposed. Fig. 1(b) shows the changes in detail made in the geometry of the component prior to performing the numerical analysis.

In this kind of problem, the number of elements and nodes considered can exceed the computer memory available to perform the numerical procedure. Moreover, the use of tools for standard mesh generation leads to several time consuming problems in components with complex geometries [25]. An alternative approach to this problem is to create a BEM sub-model. It comprises the discretization of the design only in the region where the stress concentration zone is located. According to Mellings et al. [26], a field mapping approach is used to extract the stresses from the cut surfaces of the model and convert them into equivalent tractions in the BEM sub-model. This process enables the use of BEM to predict stress fields in complex geometries.

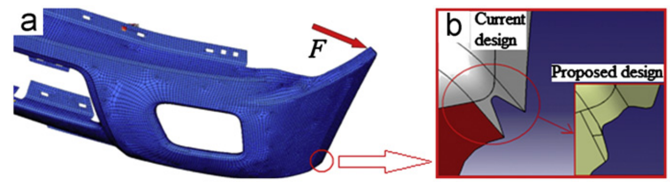

Fig. 1. Front bumper fascia (a) mesh (b) current and proposed design.

In order to implement the proposed procedure in this paper, a standard algorithm was used according to flowchart presented in Fig. 2. Additionally, this work proposes another algorithm for three-dimensional analysis using a technique called RISP (Reusable Intrinsic Sample Point) developed by Kane [27] in order to speed up the construction process of matrices G and H.

As can be seen in the flowchart (Fig. 2), the use of BEM for three-dimensional stress analysis via MatLab® is proposed. Moreover, the use of commercial software such as Catia® and Ansys® to generate the geometry and mesh of components is required. It was necessary to create files containing the input data of the problem extracted from Ansys® database. Basically, the input data comprises five files in text format containing the coordinates of all the problem nodes in a global system, the connectivity matrix between elements and nodes, the initial displacement boundary conditions for each element under clamping, the traction conditions for each element and the material properties, maximum dimension of the problem and the number of Gauss points. The main program receives the input data and converts them into vectors and matrices. The post-processing data provides the stresses around the region in question (the design change) as a consequence of the applied load.

As a first alternative, identification of possible zones of stress concentration in the component was done using historical data of failure which occurred in similar components. The knowledge and experience of the specialist can also be considered in this step. Although there are few works in the open literature on this procedure [28,29] historical data and expert knowledge are used in the automotive industry in the analysis of various vehicle components such as engine, chassis, electrics and body components. In this work, the identification of possible critical zones was performed through a mapping of stresses using FEM. In this simulation, a load (F) of 120 N was applied to the point shown in Fig. 1(a), producing the stress distribution. The critical zones were selected based on the stress values (regions with stress within the range of material yield strength, 250–350 MPa) The traction loads existing in the nodes adjacent to the critical zones were transferred to the simulation with BEM sub-model. The complete procedure comprised stress analysis using FEM, selection of the critical zones, mesh refinement to generate the BEM sub-model, transfer of traction loads in the contours of critical zones to the BEM sub-model and performing stress analysis using the BEM sub-model.

3. Results and discussions

In order to generate BEM sub-models, a small surface example was extracted from the original and the proposed design of the front bumper fascia. Fig. 3 shows the selected area for each case.

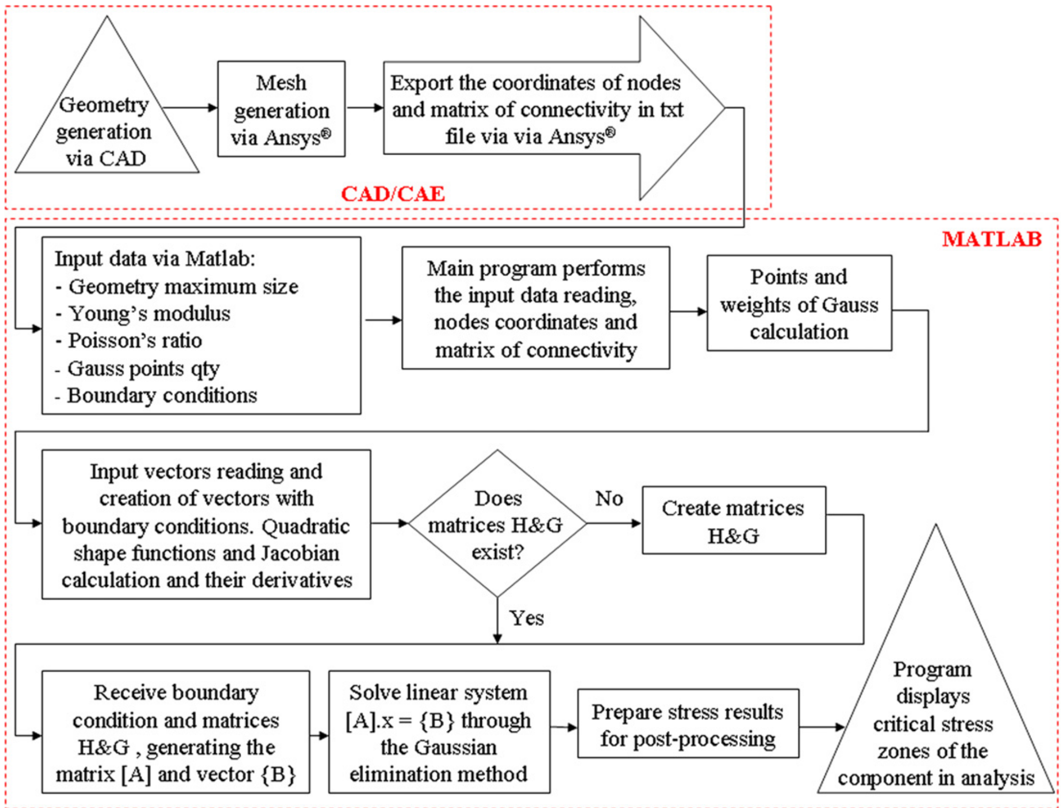

Fig. 2. Flowchart with the proposed algorithm.

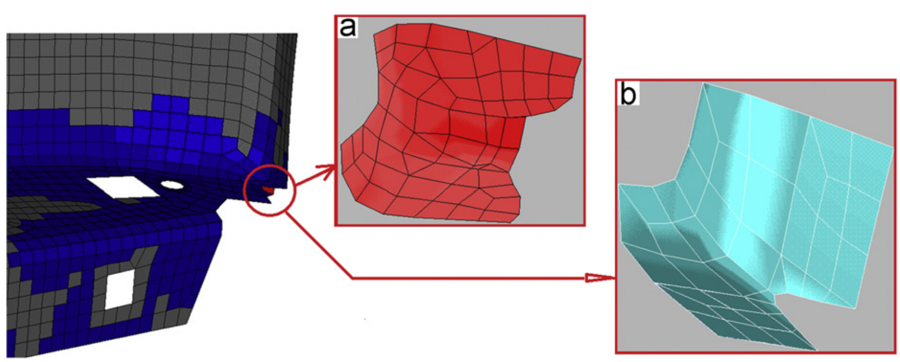

Fig. 3. Extracted surface from the proposed (a) and original design (b).

Fig. 4 shows the mesh refinement for the proposed (Fig. 4(a)) and original design (Fig. 4(b)) in order to generate the BEM sub-model for both extracted surfaces.

In the case of this work, the refined BEM sub-model generated 996 nodes and 304 elements for the original geometry and 899 nodes and 271 elements for the proposed geometry. The principal stress (σ_1) results obtained are illustrated in Fig. 5.

Based on the BEM sub-model results, it was found that the principal stresses values obtained for the original design was approximately 270 MPa (within the material yield strength range) and for the proposed design, 180 MPa (below the material yield strength range). Therefore BEM sub-model results can confirm a 28% improvement achieved by making the changes proposed in the surface of the front bumper fascia. The FEM model results show an improvement of 25% according to Fig. 6(a) and (b) (maximum stress values obtained for the original geometry was 301 MPa and for the proposed geometry, 219 MPa). These results attest to the consistency of the stress analysis performed by the proposed procedure. Furthermore, the time spent on each application (for each design) using only FEM was about 4 h. The time

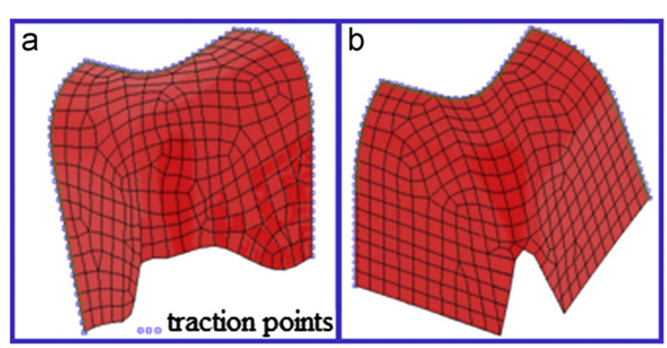

Fig. 4. Mesh refinement for the proposed (a) and original design (b).

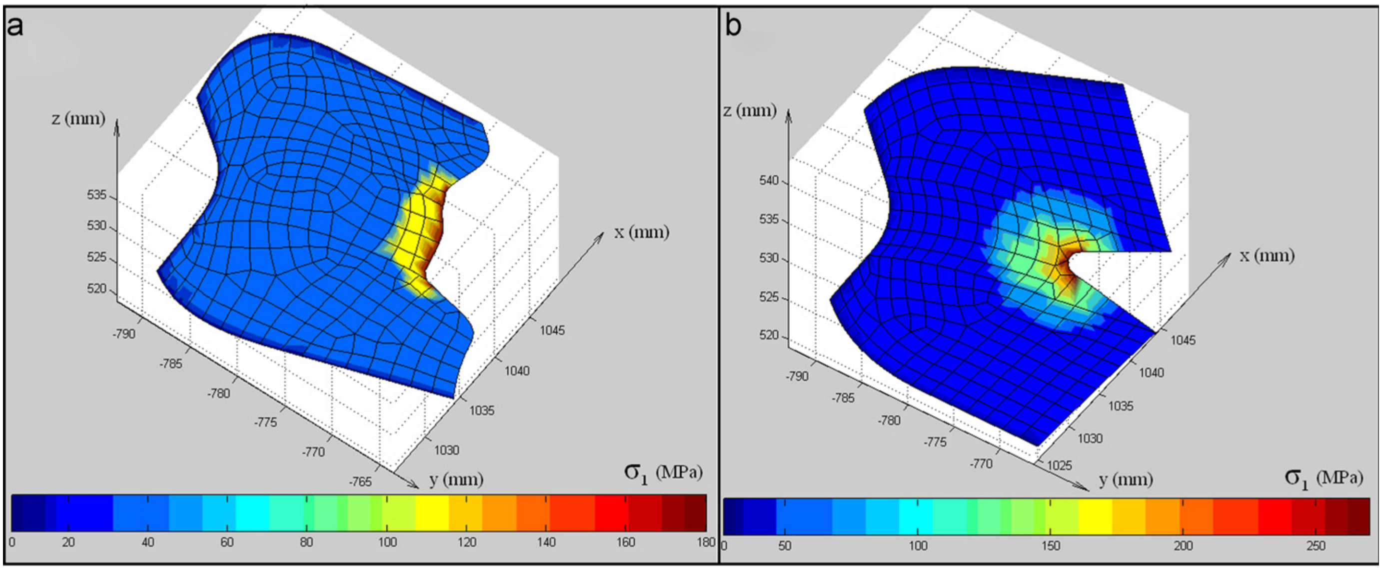

Fig. 5. BEM stress analysis for the (a) proposed and (b) original design.

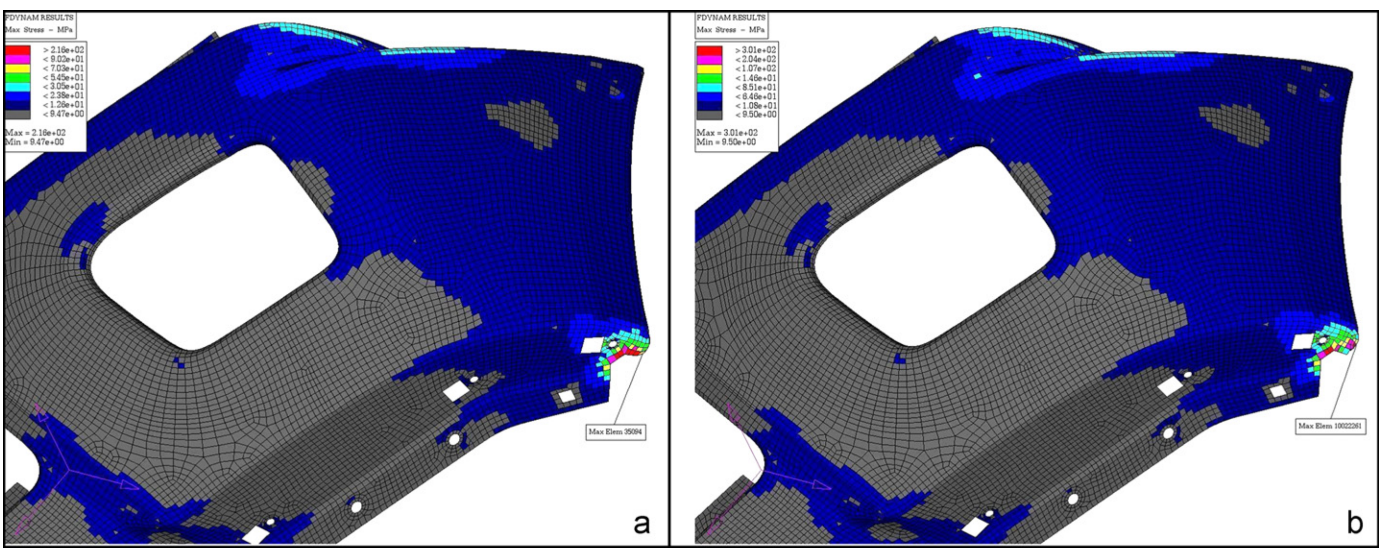

Fig. 6. FEM stress analysis for the (a) proposed and (b) original design.

spent on each application using the BEM sub-model procedure was 1.5 h (without considering the time of initial mapping of stresses carried by FEM). Additionally, the structure needed in this case does not include a dedicated workstation nor skilled labor to carry out the analysis. This demonstrates the advantage of the BEM sub-model and its potential application in the automotive industry on problems related to the prediction of stress distribution in vehicle components.

Instead of using FEM to identify possible critical zones in the component such as that exemplified in this work, it is perfectly feasible to accomplish this using historical data of failure together with expert knowledge in order to save time spent on FEM analysis.

4. Conclusions

In this work, a method for stress analysis in the automotive industry was presented. A front bumper fascia was taken as a case study. The purpose of this work was to solve a problem involving stress analysis using the BEM sub-model. In this kind of analysis BEM can be used as a powerful tool to support design changes during product development. The stress field results obtained by using BEM in this work can guide product designers to achieve better component performance in terms of structural requirements.

In the analysis of components with complex geometry, the entire BEM model requires considerable computation causing a lack of virtual memory available for simulation. In this case, the procedure presented shows that the use of local area remeshing is an alternative for decision taking about design changes.

The main contribution of using BEM to predict stress in automotive components is its simplicity. The BEM sub-model does not require dedicated workstations (which generally use computers with more than twenty gigabytes of virtual memory to process the analysis) nor specialized labor and the FEM applications similarly. Product engineers without special training in numerical analysis (CAE) can carry out the analysis on their regular computers which use about four gigabytes to perform basic work. This process will help to reduce costs and time in developing new products.

Acknowledgments

The authors acknowledge the support given by Ford Motor Company and also for their permission to publish this paper.

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