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ANALYSIS OF LOCAL STRESSES AT GIRDER-SWAY BRACING CONNECTIONS IN COMPOSITE I-GIRDER BRIDGES

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SUMMARY

A two-stage trial process to evaluate local stresses at girder-sway bracing connections of composite I-girder bridges is proposed. In the first stage, an entire bridge superstructure is analyzed as an eccentrically stiffened plate, with the use of offset beam elements,originally developed sway bracing elements and lateral bracing elements. In the second stage, a partial structure including the objective connection is zoomed out and modelled three dimensionally by thin plate elements. Calculated results are compared with measured ones.

INTRODUCTION

Recently, it is frequently reported [1,2] in both Japan and other countries that cracks are generated at girder-sway bracing connections in composite I-girder bridges. The authors presented a simple analysis method [3] for sway bracing member forces as a first step to evaluate local stresses induced at the connections which will reveal the mechanism of crack generation. The idea to take this first step is based on the facts [4] that cracks generated at the weldings between upper flanges of main girders and transverse stiffeners are discovered almost limitedly on those stiffeners to which are attached sway bracings, and that local stresses which cause cracks are considered to be generated due to sway bracing member forces.

In this paper, as the second step, a trial process to evaluate local stresses themselves, by using the results of the above mentioned sway bracings analysis <the first stage analysis >, is presented together with some numerical results in comparison with measurements on an actual bridge.

ACTUAL BRIDGES IN SERVICE AS AN OBJECT OF ANALYSIS AND STRUCTURAL DETAILS OF GIRDER-SWAY BRACING CONNECTIONS

Bridges to be analyzed in this paper are continuous composite multi-girder bridges with truss-type sway bracings, as shown in Fig.1. This type of bridge

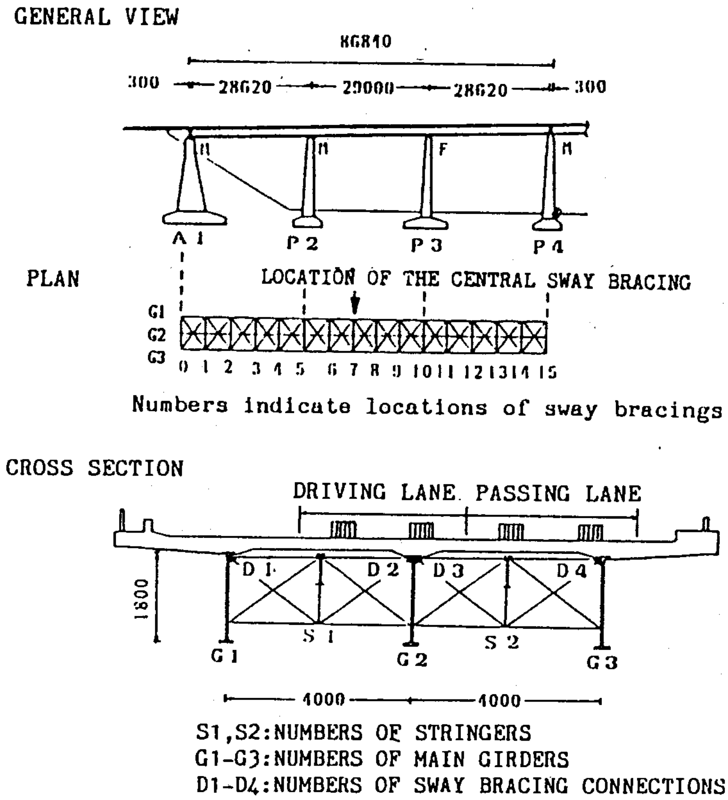


Fig. 1. Continuous composite multi girder bridge to be analyzed with truss type sway bracings

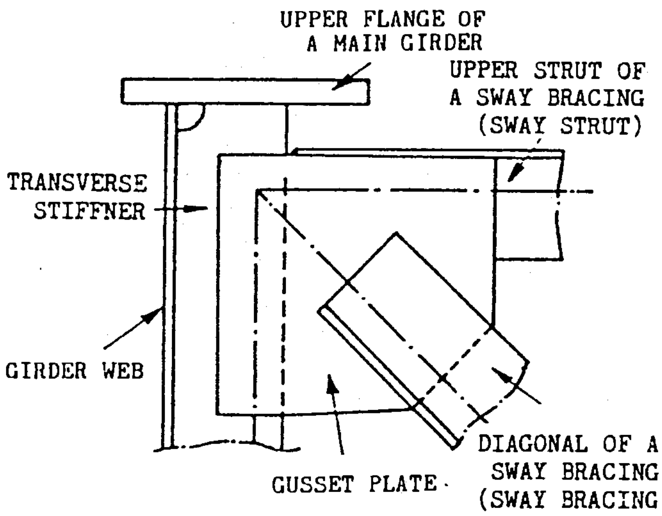


Fig. 2. Structural details at a girder-sway bracing connection (upper end of a transverse stiffner)

is one of the most typical type as high way bridges in Japan, so is the dimension illustrated in the figure. Sway bracings are usually connected with main girders through transverse stiffeners using gusset plates as shown in Fig.2. Struts and diagonals in sway bracings, gusset plates and transverse stiffeners are not placed in a single vertical plane, instead they are eccentrically connected each other by distances of plate thicknesses . This is one of the reason that there are developed local out-of-plane bending in transverse stiffeners. In this paper,the so called web-gap part between upper flange of a main girder and gusset plates is specifically concerned.

ANALYSIS METHOD

In the simple analysis method for sway bracing members proposed in Ref.[3], reinforced concrete slabs are modelled as thin plate elements, main girders and stringers offset beam element, and sway bracings as sway bracing elements. A sway bracing is firstly treated as a plane frame structure, then corresponding stiffness matrix is contracted to make that of a sway bracing element which has only those nodal degrees of freedom that plate elements have. Thus the entire superstructure of a bridge under consideration is modeled two-dimensionally as a stiffened plate. In this paper, in order to make more generalized first stage calculation, a lateral element is also introduced in the same manner with the sway bracing element.

Eccentrically stiffened plate modelling of an entire bridge superstructure

For example, in case when member forces of the center sway in the center span of the bridge in Fig.1 is going to be calculated, the entire superstruture of the bridge is modelled as an eccentrically stiffened plate as shown in Fig.3. The objective bridge in this study has bottom laterals and they are illustrated by broken lines in Fig.3. The derivation of a lateral element follows quite the same process as that for the derivation of a sway

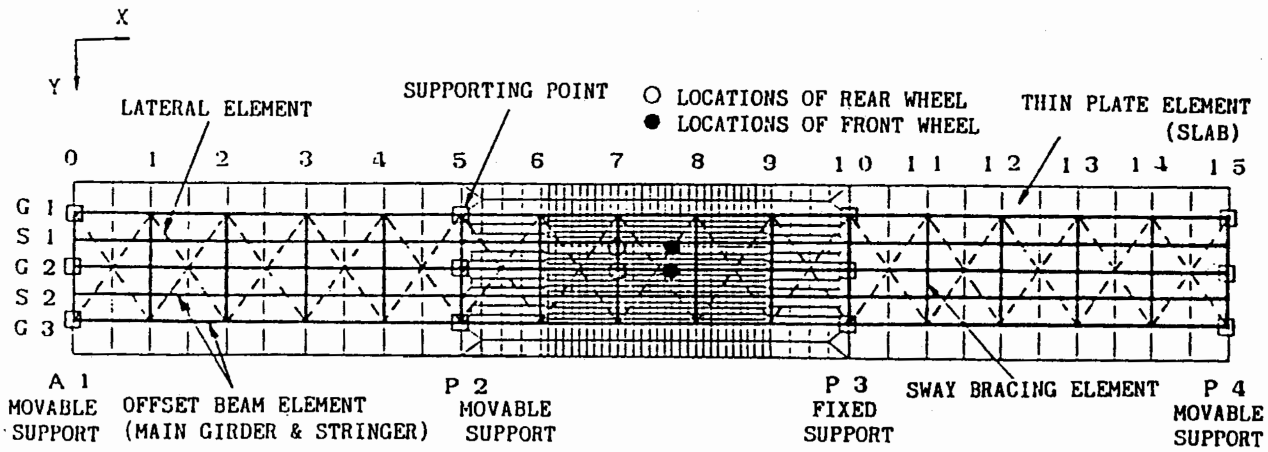
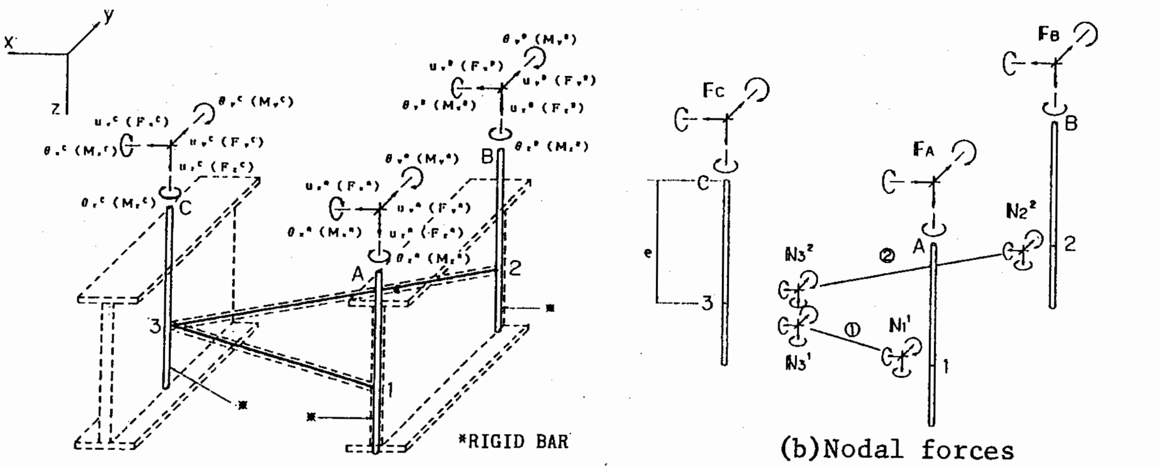


Fig. 3. Modelling of the whole bridge superstructure

bracing element [3,5]. But it should be noted that in order to make element stiffnesses by contraction, sway bracings are treated as plane frames whereas laterals are combined with virtual rigid bars located at main girders and are considered as simplest space frames. Nodal forces and nodal displacements of a lateral element are shown in Fig.4. The element has three nodes with six degrees of freedom per each node, so that eighteen degrees of freedom in total.



(a)Nodal displacements

(b)Nodal forces
A,B,C:Nodal points of a lateral element, consistent with those of plate elements describing concrete slabs

Fig. 4. Lateral frame model

<u>Local stress analysis using a zoomed 3-D partial structural model</u>

As results of the modelling and analysis of the entire bridge superstructure by the method described in the previous section, member forces of slabs, girders, stringers, sway-bracings and laterals can be obtained as well as displacements of nodal points. The local stresses at the connection between a main girder and sway bracing under consideration can be evaluate by the following manner. Firstly, a partial structure which include the part at which local stresses should be obtained is cut out from the whole structure. Then the partial structure is modelled by three dimensional plate elements as shown in Fig.5. Finally, besides the originally applied loads, each cut-out section is loaded by corresponding sectional forces obtained as the results of the previous analysis of the entire structure. In this three dimensional model,it may be more appropriate to use solid elements for haunched portion of slab, but in this study, only plate elements at hand are going to be used. Therefore, for example, slab, haunch and top flange of main girder are treated altogether as a single plate,so virtual sections are introduced to give equivalent bending and in-plane stiffnesses. As for the manner in which sectional forces of each member are distributed on to each nodal points of the partial structural model, distributed loads which can be calculated as products of plate thickness and stresses obtained from sectional forces by the elementary beam theory, are transformed to equivalent nodal forces. As for the connections between transverse stiffeners and gusset plates, and between gusset plates and sway bracing components, rigid bar elements are placed to consider the eccentricity induced by the plate thickness. An example of element division for partial structural model is illustrated in Fig.6. The entire flow chart of the proposed analysis method can be described as shown in Fig.7.

COMPARISON OF THE ANALYTICAL RESULTS AND ACTUAL MEASUREMENTS FOR THE ENTIRE STRUCTURE

Calculated slab deflections and sway bracing member forces are compared with measured values [4] in Figs.8 and 9, respectively, at the location of central sway bracing (No.7 bracing in Fig.3) in the center span in Fig.3. The loading condition is as follows; a vehicle weighing 20-tf specified in SHB

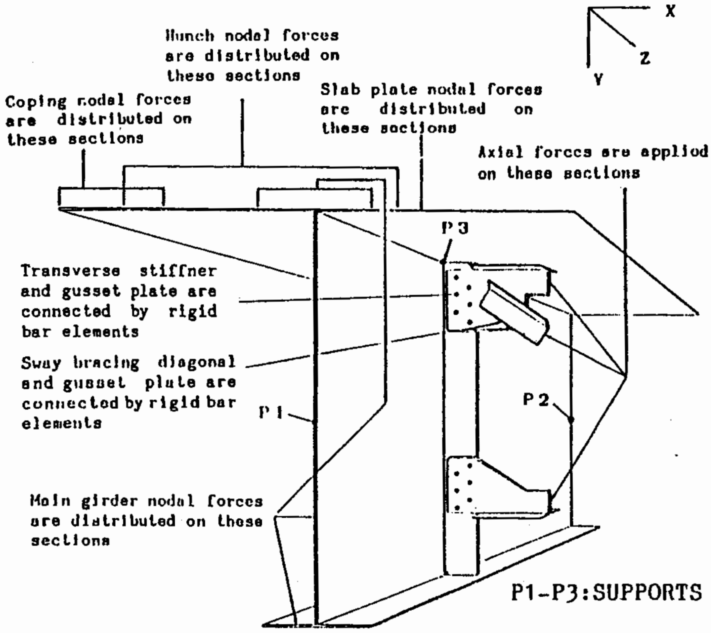


Fig. 5. Three dimensional partial structural model

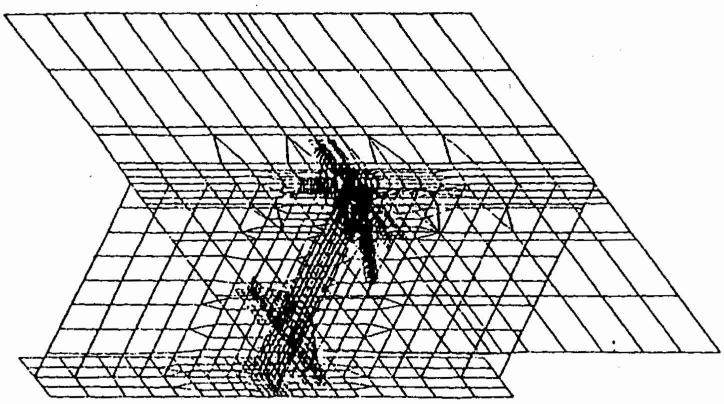


Fig. 6. Element division of the partial structure

(Japanese Specification for Highway Bridges) [6] is loaded on the driving lane, and its rear wheels are placed just above the No.7 sway bracings. The analytical values for slab deflections give about three fourths of measured values. Results obtained for the case without laterals are also illustrated in Fig.8 for reference, they are greater than the results with laterals by 5% at most. Though the actual bridge as the object of the analysis has suffered severe cracking damage in its slabs, resulting degeneration of concrete stiffness is not considered in the above calculations, since there are no efficient reliable data for the stiffness of real cracked slabs. As for the upper struts and diagonals, maximum absolute value in the measured axial force values can be found in the diagonal D1 (Fig.1). The difference between the measured and calculated values for the D1 diagonal axial force is about 2%.

As for the lower struts, the one between stringer S1 and girder G2 has an axial force with the largest absolute value. The difference between the measured and calculated values for this member is about 8%. The existence of bottom laterals has some influence on sway bracings axial forces, especially on that of lower strut, while slab deflections are not so influenced.

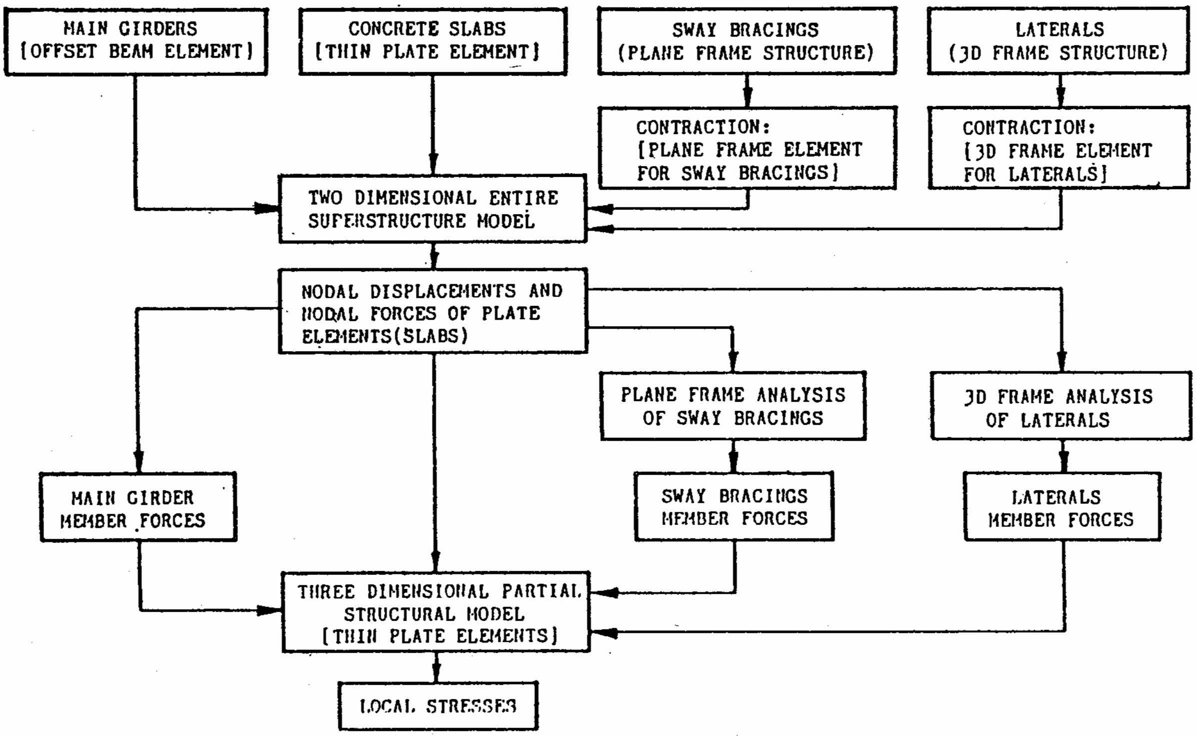


Fig. 7. Flow chart for the local stress evaluation at girder sway bracing connections in composite I-girder bridges

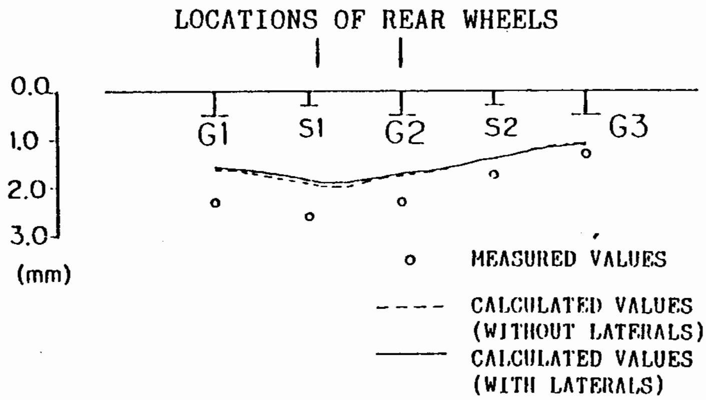
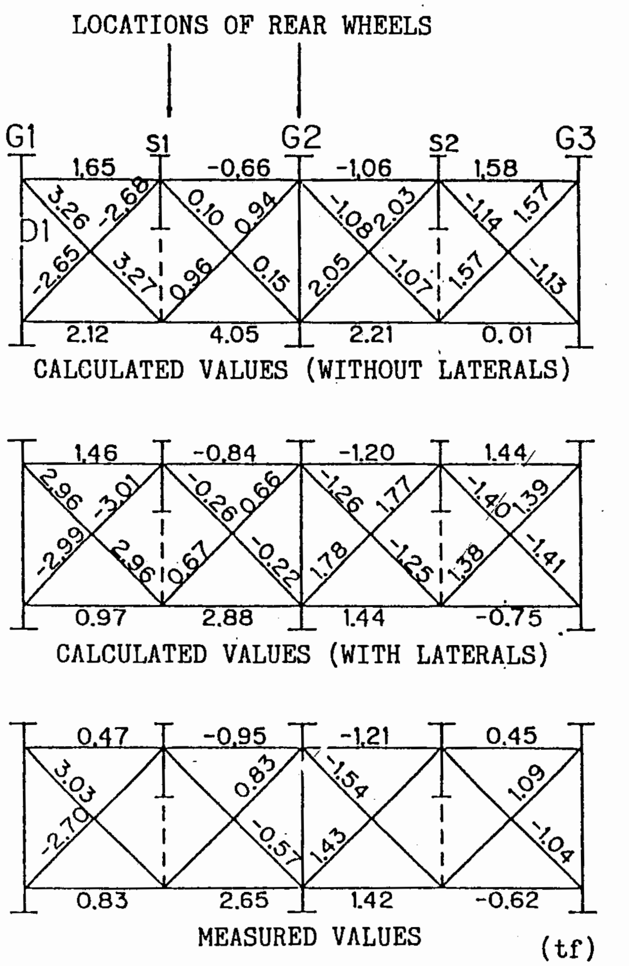


Fig. 8. Slab deflection : comparison of calculated and measured values



Tensile forces are treated as positive

Fig. 9. Axial forces in sway bracings : comparison of calculated and measured values.

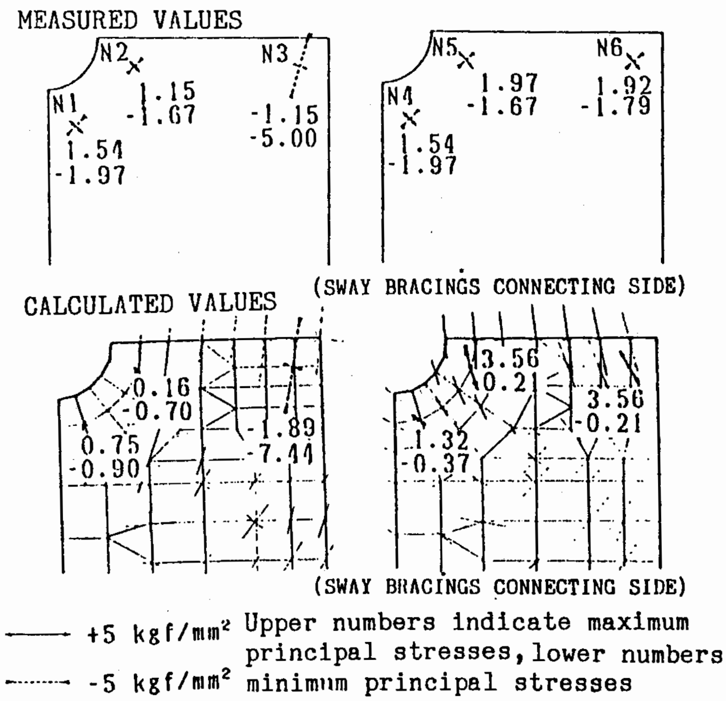


Fig. 10. Principal stresses at the upper end of a transverse stiffner : comparison of calculated and measured values.

CALCULATED RESULTS FOR LOCAL STRESSES AT GIRDER-SWAY BRACING CONNECTIONS

An example of calculated local stresses is shown in Fig.10. This calculation is made for the four-girder bridge described in Ref.4. A vehicle of 20 tf weight is loaded on the driving lane. The stresses shown are those stresses around the upper end of the transverse stiffener connected to the outer girder in transverse lane side. The actual bridge has bottom laterals, but in the entire analysis for this case, they were not considered. It is observed from the comparison between the calculated and the measured values that though the overall stress distribution is alike each other, there is a portion where the difference is over 100% in absolute values. Therefore, inclusion of bottom laterals, improvement of modelling method for the partial structure with more appropriate boundary conditions and so on are needed to get more accurate results.

CONCLUSIONS

By considering bottom laterals also, the simplified analysis method for entire bridge superstructure as a stiffened plate is revealed to be able to evaluate slab deformations as well as sway bracings member forces with sufficient accuracy. As for the local stresses themselves, an analysis process is developed in which a partial structure is modelled as a three dimensional thin plate structure, and detailed analysis is made using the results of the overall structural analysis. The result of the numerical calculations indicate the appropriateness of the basic idea of this method.

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