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Automatic Mesh Generator For 3-Dimensional Finite Element Analysis

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SYNOPSIS

The aim of this paper is to propose new automatic mesh generator for the finite element analysis of three-dimensional structures consisted of plates and beams. The strategy of the proposed one is as followings; Firstly, subdivide the structure into two-dimensional and one-dimensional structural components. Secondly, generate mesh pattern for each of them, and finally combine them so that they reconstruct the original configuration. By using the proposed method the modeling of, for example, steel bridge structures for Finite Element Analysis is easily and also fastly completed. Some examples of the application of the proposed method are presented, and from the examination of the results further important informations for the design of better method are also given in this paper.

1. INTRODUCTION

Most of steel structures in civil engineering field consist of two- and one-dimensional structural components, i.e. plate, beam, bar and truss member, and we scarecely meet with three-dimensional structural components. These two kinds of structural components are placed in three-dimensional space, and they form a three-dimensional structure.

At solving this structure Finite Element Method is commonly used,

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and the method requires the modeling of the structure. This model is called as "Finite Element Mesh System", and the procedure to generate this model is Mesh Generation.

Since most of the tedious works for the user of Finite Element Method is govened at this stage, a number of useful mesh generating methods are already proposed and in use.

The development of mesh generator is especially required at solving three-dimensional structures, because the amount of input-data required for FEM is almost proportional to the size, the complexity and the dimension of the structure being treated. But most of Mesh Generators presently in use can be applied only for two-dimensional cases.

As denoted already, most of steel structures consist of one- and two-dimensional components, and the method of generating mesh for them is relatively simple comparing with the one for three-dimensional one.

In this paper the authors propose new mesh generator which can be applied for three-dimensional structure with only two- and one-dimensional structural components.

2. AUTOMATIC MESH GENERATOR

The term "FINITE ELEMENT METHOD" generally indicates the analysis, but its program consists of three parts; PRE-PROCESSOR, ANALYSIS and POST-PROCESSOR. Pre-processor is classified into two parts; Generation of data for the analysis and Arrangement of data for solvers in Analysis part.The former is called Mesh Generation, and the latter Node-Reordering.

Necessary data for Analysis are the number of elements, the number of nodes, node-element relation, x and y coördinates of nodes, and other necessary informations as boundary nodes and so on. Mesh Generator must work to generate all of these data with the minimum tasks of the user, because as the increase of the works like key-in operations the reliability of data input necessarily decreases.

At present, we can find several automatic mesh generation methods as followings; Blocking Method, Mapping Function Method, Node Pattern Method, and Modified Quad-tree Method. If the structure has complex configuration or it consists of a number of structural components. Blocking Method becomes the most effective procedure.

Blocking Method consists of following procedures; Firstly, subdivide the structure into simpler structural components with triangular or quadrilateral configurations, secondly generate mesh patter for each of them, and finally combine them so as to reconstruct the original configuration.

Let's consider on the necessary input-data for this method when applied to two-dimensional area. In order to express the configuration of whole area, x and y coordinates of nodes, characteristics of lines connecting these nodes are at first required, and in order to subdivide it into triangular and/or quadrilateral subareas, dissection lines and sometimes some additional nodes for sufficient dissection are necessary. Moreover, the number of elements on edges of each subarea and informations on the mesh pattern are also required for the subdivision.

As obvious from above consideration on Blocking Method this method becomes effective when it has many kind of mesh patterns. Otherwise, the method becomes very stiff, and the result obtained by the method cann't satisfy the user.

By the direct extension of above method we propose new automatic mesh generator applicable for three-dimensional structures.

3. CONCEPT OF THREE-DIMENSIONAL MESH GENERATION

Let A be a space structure which consists of two- and one-dimensional structural components. Taking a plate-girder bridge as an example, we explain its structural components. Deck plate, upper and lower flanges, and web belong to the two-dimensional components, and stiffners attached on webs, bracing, and lateral members are generally treated as one-dimensional ones. From this example it is clarified that even if the configuration of structural components is almost same, their mechanical behaviours are quite different.

Now, we examine the difference between these structural models from the view point of mesh generation. Taking three structural components (i.e. deck plate, flange, and web) as examples we consider on their finite element meshes. Input-data required for mesh generation of these components are only the geometrical properties and some informations for the discretization and mesh patterns, and output data from the mesh generator are topological and geometrical properties. Therefore, at the stage of mesh generation we may separate physical properties of components from topological and geometrical properties. That is, since all of the components are placed in one of planes, i.e. x-y, y-z, and z-x planes, they can be treated as two-dimensional one, and , therefore, same mesh generator can be applied for them. Above discussion is also possible for structural components belonging to one-dimensional one.

Assume all structural components be already transformed into finite element meshes. Successively these independent meshes must be connected each other so as to reform the original configuration. At this stage, the physical property of each component plays the most important role. As an example we consider the connection of flange and web of a plate girder. Here, we assume x-axis along the direction of the girder, z-axis toward downward, and y-axis perpendicular to x-z plane. Each node on flange has 3 degree-of-freedoms, i.e. vertical displacement, angles around x and y axes, and node on web has 2 degree-of-freedoms, i.e. displacements along x and z axes. Then, after the connection of these two components, nodes on flange, on web, and on connecting edges located between them have 3, 2, and 4 degree-of-freedoms, respectively. Same discussion is also possible even for connecting same structural components. If two plates placed in different planes are jointed after generating meshes, the degree-of-freedoms of nodes on two plates and on connecting edge are different each other.

The problem mentioned above can be solved by considering the plane where the structural component locates and the characteristics of the structural component. That is, if its plane and characteristics are given at the mesh generation, the combination between blocks can be easily completed by using the informations.

Summarizing the strategy of three-dimensional mesh generator, it consists of following main three procedures;

(1) Subdivision of whole structure into a number of two- and one-dimensional structural components.

(2) Mesh generation of each structural component. Necessary mesh generator is only for two- and one-dimensional components.

(3) Reconstruction of meshed structural components into the original confguration by considering the location of each component and its structural characteristics.

4. PROCEDURES OF THREE-DIMENSIONAL AUTOMATIC MESH GENERATOR

Flow-chart of the mesh generator proposed in this paper is given in Fig.1, and the explanation of steps in the chart are also given. It consists of following 7 steps; At the first step "INPUTD" all the

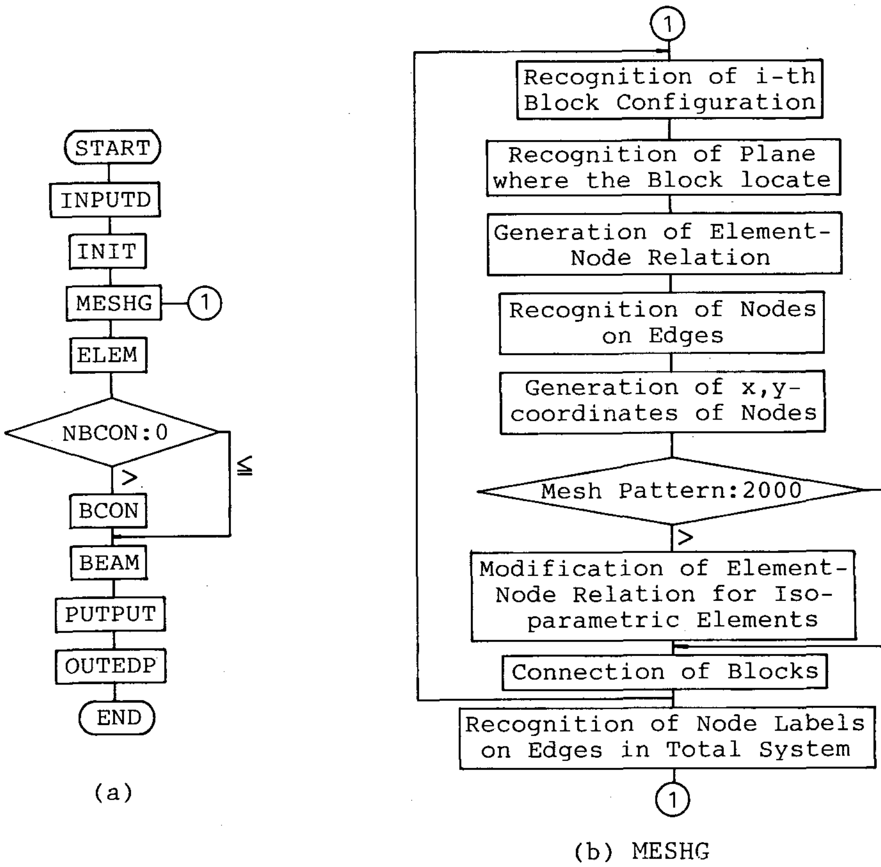

Fig.1 Flow-chart of Proposed Mesh Generator

necessary data are input by the user, at the second step "INIT" all variables are cleared, at the third step "MESHG" structural components are successively transformed into meshed one in accordance with the informations given in the first step. Step "ELEM" works to give physical properties components given in the first step. At the process of "NBCON" all informations concerning with the boundary conditions are generated in accordance with the input data, "BEAM" works for generating one-dimensional mesh like beams and combine them into the data generated in "MESHG", and "OUTPUT" works for the generation of the relation between nodes and degree-of-freedom and also for output of all data to file, and "OUTEDP" is for output of labels of nodes locating on all edges of blocks to another file.

Explanation of Processes

1. INPUTD

All the data necessary for use this mesh generator are input in this step, and they are summarized as followings;

IBLOCK ; Number of blocks

IEDGE ; Number of edges necessary to draw the structure

KNODE ; Number of nodes necessary to draw the structure

IFIG ; Configuration of each block (IBLOCK)
"3" for Triangular Block
"4" for Quadrilateral Block

ITYPE ; Mesh pattern for each block . (IBLOCK)
Mesh pattern is presented by using 4 figures. The first figure indicates the property of the element, the second the configuration of block, the third the configuration of element, and the last figure the sequential number of the model. For example, mesh pattern of "1441" indicates a mesh generation of a quadrilateral area into constant rectangular elements. Mesh pattern of "2331" indicates the one for a triangular area into 6-node isoparametric triangular elements. (See Fig.2)

IBLED ; Relation between blocks and edges
(IBLOCK,IFIG(IBLOCK))

INUM ; Number of elements on edges
(IBLOCK,IFIG(IBLOCK))

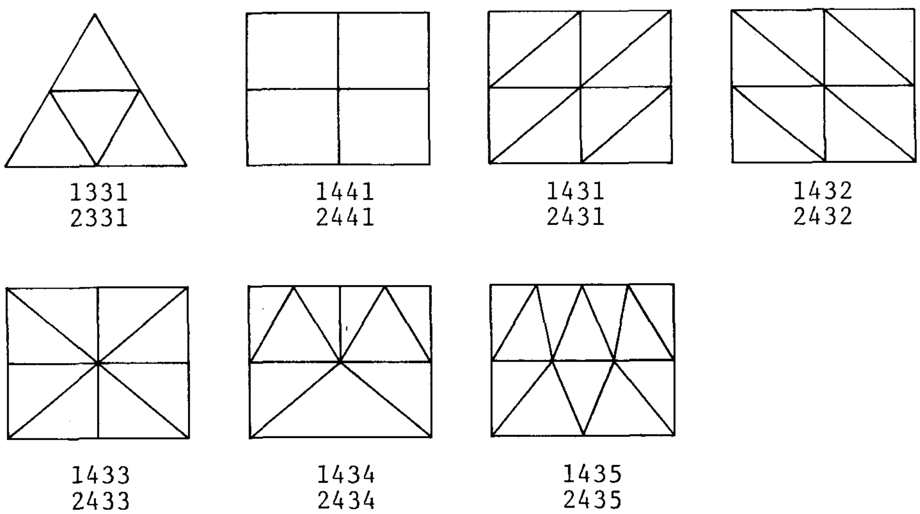

Fig.2 Mesh Patterns

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KBLMAP     ; Relation between block and degree-of-freedom
              (IBLOCK,6)
YMBL       ; Young's Modulus of blocks  (IBLOCK)
POISBL     ; Poisson's Ratios of blocks  (IBLOCK)
THKBL      ; Thickness of blocks  (IBLOCK)
NPAR       ; Selection of plane stress or plane strain
             analysis  (IBLOCK)
              "0" for Plane Stress Analysis
              "1" for Plane Strain Analysis
IEDNO      ; Relation between edges and nodes (IEDGE,2)
R          ; Radius of edges  (IEDGE)
              "-r" for a positively curved edge
              "0.0" for a straight edge
              "r" for a negatively curved edge
P          ; x, y and z coordinates of nodes
              (KNODE,3)
NBCON      ; Number of loading cases for analysis
NBCB       ; Number of blocks subjecting loadings (NBCON)
NBCL       ; Number of edges subjecting boundary conditions,
             i.e. force or displacement (NBCON)
NBCP       ; Number of nodes subjecting boundary conditions,
             i.e. force or displacement (NBCON)
IBCB       ; Labels of blocks included in NBCB
              (NBCON,NBCB(NBCON))
NBB        ; Kind of boundary conditions for block
              "1" for giving displacement for node
              "2" for zero displacement for node
              "3" for loading on node
              (NBCON,NBCB(NBCON))
KBCB       ; Direction of boundary condition for block
              "1" for along x-axis
              "2" for along y-axis
              "3" for along z-axis
              "4" for around x-axis
              "5" for around y-axis
              "6" for around z-axis
              (NBCON,NBCB(NBCON))
FB         ; Intensity of force and displacement for block
              (NBCON,NBCB(NBCON))
IBCL       ; Labels of edges included in NBCL
              (NBCON,NBCB(NBCON))
```

NBL	;	Kind of boundary conditions for edge Refer to NBB
KBCL	;	Direction of boundary condition for edge Refer to KBCB
FL	;	Intensity of force and displacement on edge Refer to FB
IBCP	;	Labels of nodes included in NBCP (NBCON,NBCB(NBCON))
NBP	;	Kind of boundary conditions for node Refer to NBB
KBCP	;	Direction of boundary condition for node Refer to KBCB
FP	;	Intensity of force and displacement at node Refer to FB
IBE	;	Number of edges where beams are placed
IEDBE	;	Labels of edges where beams are placed (IBE)
MBEMAP	;	Degree-of-freedom of beam (IBE,6)
YMBL	;	Young's Modulus of beams (IBE)
AREA	;	Sectional area of beams (IBE)
XIXX	;	Sectional moment of inertial of beams (IBE)

2. INIT

In this subroutine all variables are set to be zero, and it prepares for the successive computations.

3. MESHG

Each block in a two-dimensional plane is transformed into mesh system by using the input data. Details of this process is shown as a flow-chart in Fig.1-b.

This process mainly consists of a number of subroutines which generate various types of mesh patterns. All of these mesh generators are for two-dimensional area with triangular and quadrilateral configurations. (See Ref.1.)

Another important procedure included in this step is the connection of blocks after their mesh generation. By taking the plane where each block locates into consideration blocks are successively jointed one after another when they are transformed into meshed one.

4. ELEM

In this step all the physical and some geometrical properties are given to all finite elements by using the data input in INPUTD. This step can largely save the tedious works of the user.

5. IF JUDGEMENT OF NBCON

This process is repeated as the number of NBCON in order to generate all the necessary informations for boundary conditions.

6. BCON

This process generates all of the informations concerning boundary conditions, for example, labels of nodes which subject some kinds of boundary conditions, its kind, the direction of force and displacement, and also its intensity. This step is designed in order to decrease the tedious works of users.

7. BEAM

In this subroutine the data for beam element are generated accoding to the input data, and they are stored in appropriate place. If beams are attached on plate structure, mesh generation for them is not applied and necessary data from the ones of plate components are introduced.

8. OUTPUT

The main purposes of this subroutine are the generation of node degree-of-freedom relation and output of generated data to auxiliary file. The data stored in the file are as followings;

NODE ; Total number of nodes
NELM ; Total number of elements except beam elements
NELMT ; Total number of elements including beam elements
IBLOCK ; Total number of blocks except beams
IBLT ; Total number of blocks including beams
NTJD ; Total number of degree-of-freedom
NBCON ; Number of loading cases
ICON ; Number of constraints
XNODE ; x-coordinate of nodes (NODE)
YNODE ; y-coordinate of nodes (NODE)
ZNODE ; z-coordinate of nodes (NODE)
NPMAP ; Node degree-of-freedom relation (NODE,6)
MTJ ; Element node relation (NELMT,8)
INDEX1 ; Label of the first element of each block (IBLT)
KBLMAP ; Block degree-of-freedom relation (IBLT,6)
NPAR ; Selection of plane stress or strain analysis (IBLT)
YM ; Young's modulus of each element (IBLT)
POIS ; Poisson's ratio for 2-D elements and Moment of inertia for 1-D elements (NELMT)
AR ; Area for 2-D elements and Sectional area for 1-D elements (NELMT)
THICK ; Thickness of 2-D elements (0.0 for 1-D elements) (NELMT)
IPBCON ; Labels of nodes subjecting boundary conditions

(NBCON,ICON(NBCON))

IPNB ; Kinds of boundary conditions
(NBCON,ICON(NBCON))

IPMAP ; Directions of boundary conditions
(NBCON,ICON(NBCON))

FOST ; Intensity of loading or scale of displacement
(NBCON,ICON(NBCON))

5. APPLICATION OF PROPOSED MESH GENERATOR

In this section the proposed method is actually applied for the generation of finite element models of three-dimensional structures, and we explain the procedure of its application and also the results.

In order to explain how to use new mesh generator a simple three-dimensional configuration shown in Fig.3-a is treated. In this case the structure is subdivided into three blocks all of which are two-dimensional structural components. Among these components A and B components are treated as plate, and the component indicated as C is treated as in-plane structure. The input-data necessary for generating mesh are presented in Appendix, and the generated mesh system is

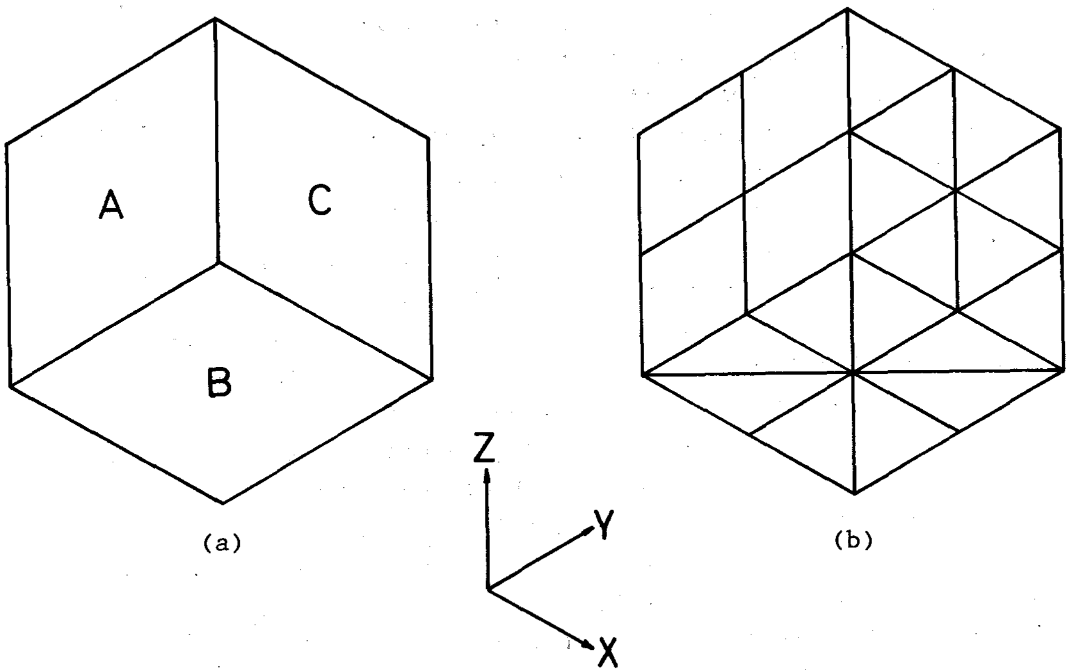

Fig.3 Simple Example of Mesh Generation

illustrated in Fig.3-b.

The first example of the application to an actual structure is shown in Fig.4. The structure treated here is a portion of plate girder which consists of upper flange, lower flange, web, vertical and lateral stiffners. Flanges are treated as plate, web and stiffners as in-plane two-dimensional structural components. Whole mesh system and the meshes of structural components are illustrated in the same figure.

A box-type girder is selected as the second example of its application, and its details are shown in Fig.5. In this case upper and lower flanges are plate-like structural components, and two web plates and diaphrams are in-plane two-dimensional structural components. The figure shows the the mesh graphs of total and also its six components.

Above two examples show that the method can be applicable as a mesh generator for actual three-dimensional structures.

6. SOME REMARKS ON PROPOSED METHOD

The aims of this section are the inspection of the proposed strategy, to remark some important points for its improvement, and the proposal of actual methods for it.

The results in previous section clarify that the proposed mesh generator can be enoughly applied as an effective method to actual three-dimensional structures, and this indicates the aim of this study is sufficiently attained.

But, careful inspection on these two examples shows following point which should be improved: Proposed method requires numerous input-data, and the amount increases in accordance with the number of blocks treated in the method.

In the first example the structure consists of only five structural components, and the second structure has six. On the other hand, the number of blocks treated in both cases is more than 20 and 14, respectively. This increase of the number of blocks is caused by following two reasons;

1). The joint between blocks can be done only at edges of blocks.

2). Blocks must have triangle or quadrilateral configuration.

In order to overcome above demerits following new procedures are required; More flexible connection method between blocks and flexible mesh generator for block. That is, former indicates that the

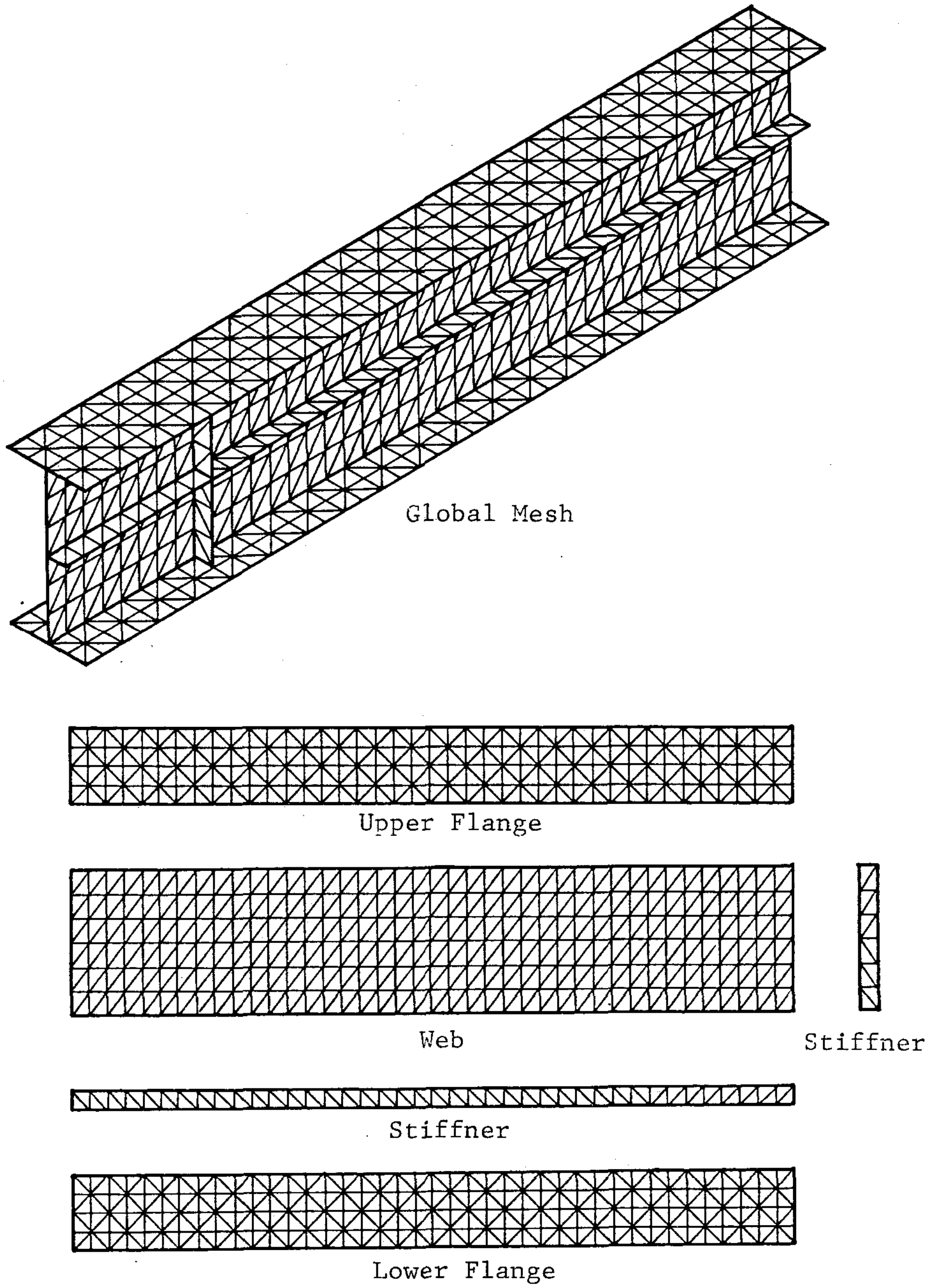

Fig.4 Mesh System of Girder

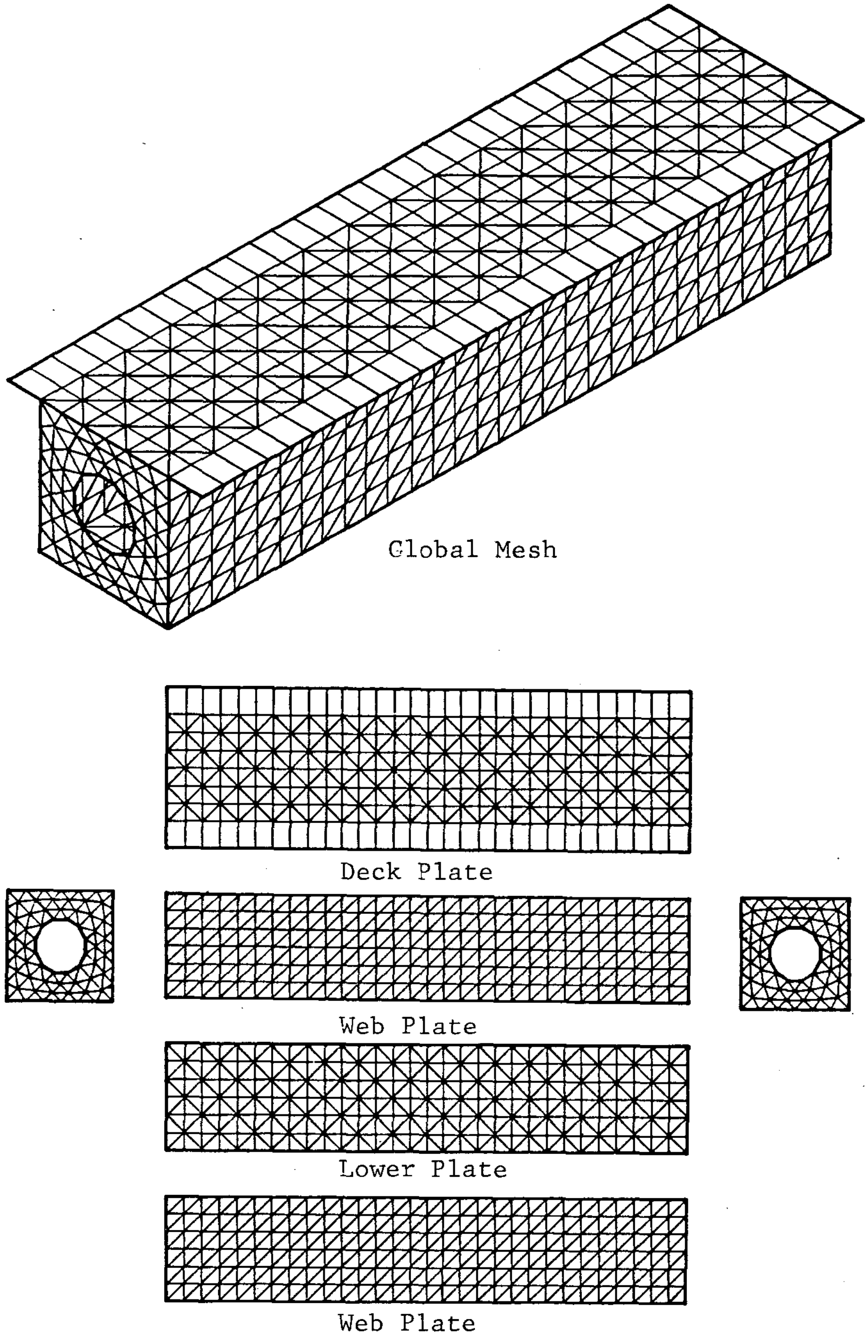

Fig.5 Mesh System of Box Girder

connection of a block to another one should be allowed at any place of the block, and the latter suggests that more preferable mesh generator is the one which can be applied for N-polygonal configuration with N > 4.

7. CONCLUDING REMARKS

In this paper new automatic mesh generator for 3D-structure was proposed and its effectivity was shown through application to actual bridge structures. At the same time the examples clarified that there still exists some points which should be improved.

This demerit of the proposed method originally is induced by the strategy of Blocking Method. That is, Blocking Method generates total mesh system by gathering mesh pattern of blocks. Therefore, it necessarily requires two processes of generation of mesh for blocks and the connection method between them.

In order to overcome this demerit more flexible connection method and also more flexible mesh generator for blocks must be proposed.

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REFERENCES

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APPENDIX

- INPUT DATA -

```
    IBLOCK, IEDGE, KNODE
    DO 10 I=1,IBLOCK
    IFIG(I),ITYPE(I),(IBLED(I,J),J=1,IFIG(I)),(INUM(I,J),J=1,IFIG(I))
 10 (KBLMAP(I,J),J=1,6), YMBL(I), POISBL(I), THKBL(I), NPAR(I)
    DO 20 I=1,IEDGE
 20 (IEDNO(I,J),J=1,2), R(I)
    DO 30 I=1,KNODE
 30 (P(I,J),J=1,3)
    NBCON
    DO 40 I=1,NBCON
    NBCB(I), NBCL(I), NBCP(I)
    DO 50 J=1,NBCB(I)
 50 IBCB(I,J), NBB(I,J), KBCB(I,J), FB(I,J)
    DO 60 J=1,NBCL(I)
 60 IBCL(I,J), NBL(I,J), KBCL(I,J), FL(I,J)
    DO 70 J=1,NBCP(I)
 70 IBCP(I,J), NBP(I,J), KBCP(I,J), FP(I,J)
 40 CONTINUE
```

```
 3     9     7
 4  1441     1     2     3     4     2     2     2     2
 1     0     0     0     1     1  2100000.0        0.3        1.0     0
 4  1433     3     8     9     6     2     2     2     2
 0     0     1     1     1     0  2100000.0        0.3        1.0     0
 4  1432     6     4     5     7     2     2     2     2
 1     0     1     0     0     0  2100000.0        0.3        2.0     0
 1     3        0.0
 1     2        0.0
 2     4        0.0
 3     4        0.0
 3     5        0.0
 4     6        0.0
 5     6        0.0
 7     2        0.0
 7     6        0.0
     0.0        0.0      100.0
     0.0        0.0        0.0
     0.0      100.0      100.0
     0.0      100.0        0.0
   100.0      100.0      100.0
   100.0      100.0        0.0
   100.0        0.0        0.0
 1
 0     1     4
 9     2     3        0.0
 2     2     3        0.0
 4     2     3        0.0
 5     2     1        0.0
 7     2     2        0.0
```

- OUTPUT DATA -

```
   NODE, NELM, NELMT, IBLOCK, IBLT, NTJD, NBCON
   (ICON(I),I=1,NBCON)
   DO 10 I=1,NODE
10 XNODE(I), YNODE(I), ZNODE(I), (NPMAP(I,J),J=1,6)
   DO 20 I=1,NELMT
20 (MTJ(I,J),J=1,8)
   DO 30 I=1,IBLT
30 INDEX1(I), (KBLMAP(I,J),J=1,6), NPAR(I)
   INDEX1(IBLT+1)
   DO 40 I=1,NELMT
40 YM(I), POIS(I), AR(I), THICK(I)
   DO 50 I=1,NBCON
   DO 50 J=1,ICON(I)
50 IPBCON(I,J), IPNB(I,J), IPMAP(I,J), FOST(I,J)
```

```
19   20   20    3    3   63    1
 7
0.               0.1000000E+03  0.1000000E+03  1  0  1  0  1  1       1NODE
0.               0.5000000E+02  0.1000000E+03  1  0  0  0  1  1       2NODE
0.               0.             0.1000000E+03  1  0  0  0  1  1       3NODE
0.               0.1000000E+03  0.5000000E+02  1  0  1  0  1  1       4NODE
0.               0.5000000E+02  0.5000000E+02  1  0  0  0  1  1       5NODE
0.               0.             0.5000000E+02  1  0  0  0  1  1       6NODE
0.               0.1000000E+03  0.             1  0  1  1  1  1       7NODE
0.               0.5000000E+02  0.             1  0  1  1  1  1       8NODE
0.               0.             0.             1  0  1  1  1  1       9NODE
0.5000000E+02    0.5000000E+02  0.             0  0  1  1  1  0      10NODE
0.5000000E+02    0.1000000E+03  0.             1  0  1  1  1  0      11NODE
0.5000000E+02    0.             0.             0  0  1  1  1  0      12NODE
0.1000000E+03    0.1000000E+03  0.             1  0  1  1  1  0      13NODE
0.1000000E+03    0.             0.             0  0  1  1  1  0      14NODE
0.1000000E+03    0.5000000E+02  0.             0  0  1  1  1  0      15NODE
0.1000000E+03    0.1000000E+03  0.5000000E+02  1  0  1  0  0  0      16NODE
0.5000000E+02    0.1000000E+03  0.5000000E+02  1  0  1  0  0  0      17NODE
0.1000000E+03    0.1000000E+03  0.1000000E+03  1  0  1  0  0  0      18NODE
0.5000000E+02    0.1000000E+03  0.1000000E+03  1  0  1  0  0  0      19NODE
 1    2    5    4    0    0    0    0         1ELEMENT
 2    3    6    5    0    0    0    0         2ELEMENT
 4    5    8    7    0    0    0    0         3ELEMENT
 5    6    9    8    0    0    0    0         4ELEMENT
 7    8   10    0    0    0    0    0         5ELEMENT
 8    9   10    0    0    0    0    0         6ELEMENT
 7   10   11    0    0    0    0    0         7ELEMENT
 9   12   10    0    0    0    0    0         8ELEMENT
11   10   13    0    0    0    0    0         9ELEMENT
10   12   14    0    0    0    0    0        10ELEMENT
10   15   13    0    0    0    0    0        11ELEMENT
10   14   15    0    0    0    0    0        12ELEMENT
13   11   16    0    0    0    0    0        13ELEMENT
11    7   17    0    0    0    0    0        14ELEMENT
11   17   16    0    0    0    0    0        15ELEMENT
 7    4   17    0    0    0    0    0        16ELEMENT
16   17   18    0    0    0    0    0        17ELEMENT
17    4   19    0    0    0    0    0        18ELEMENT
17   19   18    0    0    0    0    0        19ELEMENT
 4    1   19    0    0    0    0    0        20ELEMENT
```

```
  1    1    0    0    0    1    1    0          1BLOCK
  5    0    0    1    1    1    0    0          2BLOCK
 13    1    0    1    0    0    0    0          3BLOCK
 21                                             4BLOCK
0.2100000E+07   0.3000000E+00   0.2500000E+04   0.1000000E+01          1ELEMENT
0.2100000E+07   0.3000000E+00   0.2500000E+04   0.1000000E+01          2ELEMENT
0.2100000E+07   0.3000000E+00   0.2500000E+04   0.1000000E+01          3ELEMENT
0.2100000E+07   0.3000000E+00   0.2500000E+04   0.1000000E+01          4ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01          5ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01          6ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01          7ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01          8ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01          9ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01         10ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01         11ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.1000000E+01         12ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         13ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         14ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         15ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         16ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         17ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         18ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         19ELEMENT
0.2100000E+07   0.3000000E+00   0.1250000E+04   0.2000000E+01         20ELEMENT
14    2    3    0.                      1H.C.
15    2    3    0.                      1H.C.
13    2    3    0.                      1H.C.
 9    2    3    0.                      1H.C.
 7    2    3    0.                      1H.C.
18    2    1    0.                      1H.C.
14    2    2    0.                      1H.C.
```