

Smart System for Generating Plane Frame Problems with Joint Loads in Structural Analysis Education

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Abstract: One of the main problems that face teaching structural analysis is the creation of problems to evaluate the student level. The professor has to create many problems as solved examples, make effort to solve these problems, and try to create other problems to evaluate the students. A main challenge that faces the professor is the high possibility of errors and repeating some problems. The main aim of this paper is to construct a smart system that generates automatically a huge number of plane frame problems using the principals of database to be used in structural analysis education. This paper shows how to convert the ideas that are stored in the professor brain into a database rules.

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1. Introduction

In general, most students in engineering disciplines have difficulty in understanding fundamental concepts and basic principles. One reason for this shortage in student learning may be that the classical lecture-mode of teaching by itself is not sufficient for students to understand basic concepts. The learning style of students may vary in many different ways such as seeing and hearing, reasoning logically and intuitively, reflecting and acting, memorizing and visualizing, and building mathematical models. The teaching methods also vary between instructors. Some instructors like to lecture, others demonstrate or discuss, one may focus on principles and other on applications, some may stress on memorizing and others may give more attention for understanding [1-5]. As a result of these variations in the learning styles of students and the teaching styles of instructors, a great amount of research effort has been directed to address this issue in education [6-9].

How to introduce substantial educational change and improve quality has been the concern of educational planners for many years. This concern with quality has progressively shifted its focus from input to outcomes in terms of learning achievement [10].

The structural analysis is an essential course in civil engineering. Many researches tried to enhance the education of structural analysis [11-14]. After teaching this course in enhanced method, it is required to evaluate the student levels, which require many problems with their solution. The professor has to create many problems as solved examples, make effort to solve these problems, and try to create other problems to evaluate the students. A main challenge that faces the professor is the high possibility of

errors and repeating some problems. The effort that is done in creating problems includes: the selection of structure shape, putting the supports, check the stability of the structure, select the load type and the location of loads as shown in Fig. 1. If it is required to generate a huge number of problems with high quality, it will take a long time with high risk of errors. The advance in computer science directs us to use it in creating, solving, drawing problems and testing students. These are four main stages in the road of assessment of structural analysis education.

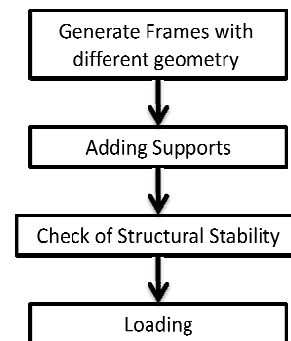


Figure 1: Flow chart of Generating frame structure problems system

2. Research objectives

The objective of this research is to develop a smart system that generates a high speed and high quality structural analysis problems. The smart system is designed using the principal of database. This research focuses on the transformation of the ideas that are stored in professor brain into a database rules. In this paper, the steps of designing the smart system are explained. The structure of the tables in the proposed database is shown.

3. System procedures

The generation of plane frame problems follows many steps. At first, generate the frame structures with different shapes, then adding the supports to the frames and checking the frames stability, then adding the loads. This procedure is summarized in Fig. 1.

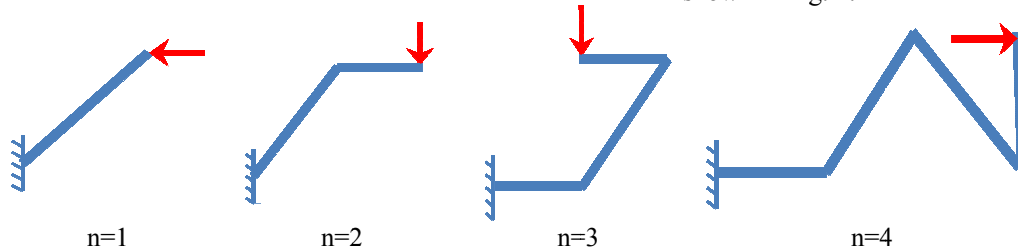


Figure 2: Frame structures with different number of elements

3.1 Generating the Main Frame

Generation of frame structure problems depends on some parameters. The first parameter that must be selected when creating a frame structure problem is the number of elements (n). This parameter determines the level of complexity of the problems as shown in Fig. 2.

The second parameter is the main angles of the elements. The angles may take unlimited values. However, it is preferred to select clear distinct angles to avoid ambiguous solutions. The joint coordinates depend mainly on the element angles and the element lengths which may also take unlimited values. The structure of the element angles table is shown in Table 1. The two fields "Element Dx" and "Element

Dy" can be calculated from the element length and the element angle, i.e. they are redundant fields. Adding redundant fields helps in improving the performance of the database. The process of attempting to optimize the read performance of a database by adding redundant data or by grouping data is known as Denormalization [15, 16]. Some values that stored in Table 1 are shown in Table 2.

Table 1: The element angles table structure.

#	Filed Name	Field Type	Field Description
1	ElementAngleID	Long Integer	Identified Number
2	ElementAngle	Double	Angle of Element
3	ElementLength	Double	Length of Element
4	ElementDx	Double	Horizontal projection of element length
5	ElementDy	Double	Vertical projection of element length

Table 2: Values stored in element angles table

Element AngleID	Element Angle	Element Length	ElementDx	ElementDy
1	0	4	4	0
2	45	5.657	4	4
3	90	4	0	4
4	135	5.657	-4	4
5	180	4	-4	0

To generate the main frames with different shapes, it is required to make a mutual combination of the element angles. A Second table is constructed

to store the angles of the main frames. The structure of this table is shown in Table 3.

Table 3: The frame element angles table structure

#	Filed Name	Field Type	Field description
1	StrElemAngleID	Long Integer	Auto-increment number
2	StrElemID	Long Integer	Identified number for Structure
3	ElemSequence	Long Integer	Sequence of element
4	ElementAngleID	Long Integer	Identified number for angle

The fields named "StrElemID", "ElemSequence" and "Element Angle ID" indicate a serial of the main frame structure, the sequence of the

element in the main frame structure and the number of the angle which linked to table 1. Some values that stored in this table are shown in Table 4.

Table 4: Some values stored in Structure element angles table

StrElemAngleID	StrElemID	ElemSequence	ElementAngleID
1	2	1	2
2	2	2	1
3	3	1	3
4	3	2	1
5	4	1	4
6	4	2	1
7	6	1	1
8	6	2	2

The values presented in Table 4 show four main frame structures numbered (2, 3, 4 and 6). Each structure has two elements with two angles. The first frame numbered 2 has two elements with angles 45 and 0 respectively. The second frame numbered 3 has

two elements with angles 90 and 0 respectively. The third frame numbered 4 has two elements with angles 135 and 0 respectively. The fourth frame numbered 6 has two elements with angles 0 and 45 respectively as shown in Fig. 3.

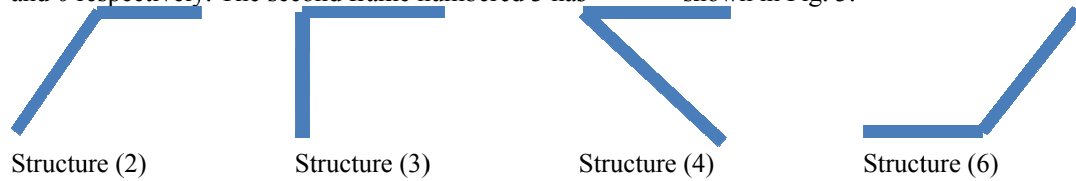


Figure 3: Sample of main frame structures

To fill this table it is required to make a cross join combination between the element angles table as many times as the number of elements requires; as

shown in Fig. 4 when the number of elements is three.

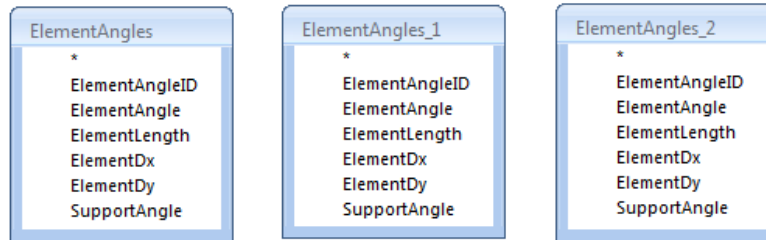


Figure 4: Cross join combination of element angles

Diagram for a frame that consist of three elements
The "elementAngleID" filed is pasted from all tables into a temporary table TT1. Table 5

presents the design of the temporary table TT1. In Table 5, the field named "ID" is an auto increment field.

Table 5: Temporary table TT1 structure

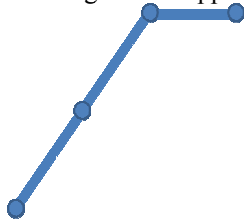
#	Filed Name	Field Type	Field description
1	ID	Long Integer	Auto increment Number
2	ElementAngleID1	Long Integer	ID of the first element Angle
3	ElementAngleID2	Long Integer	ID of the second element Angle
4	ElementAngleID3	Long Integer	ID of the third element Angle

Then the values in this temporary table is pasted individually into the frame element angles table

where the "StrElemID" field accommodates the "ID" field, the "ElementAngleID" field accommodates the

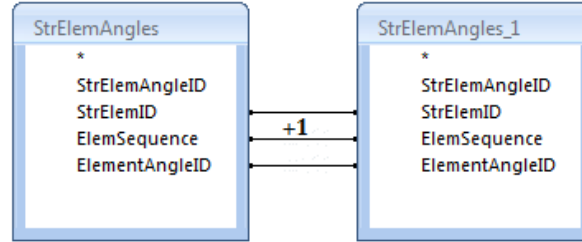
"ElementAngleID" field in the temporary table while filling the "ElemSequence" field with serial number according to the pasted column (i.e. sequence 1 for field "ElementAngleID1" and sequence 2 for field "ElementAngleID2", etc.).

In this stage, it is required to delete the structure problems that have two successive elements with the same angle or opposite angles, because those



(a) Problem

problems can cause confusion with frames that have smaller number of elements as shown in Fig. 5a. To capture those problems, the frame element angles table was linked twice with increasing one in the element sequence for the same frame and the same angle as shown in Fig. 5b.



(b) Solving

Figure 5: Sequential elements with the same angle

The next table is the frame point's coordinates that will be used later in calculating the reactions and internal forces in the frames and in checking the

stability of frame problems. The structure of the frame points table is shown in Table 6.

Table 6: Frame points table structure

#	Filed Name	Field Type	Field description
1	StrElemPointID	Long Integer	Auto increment Number
2	StrElemID	Long Integer	Identified number for the frame shape
3	StrElemPointNo	Long Integer	Sequence of point in the frame
4	StrElemPointx	Double	Point x coordinate
5	StrElemPointy	Double	Point y coordinate

The fields "StrElemPointx" and "StrElemPointy" describe the coordinates of the point number "StrElemPointNo" in the frame labeled "StrElemID". This table is filled initially with the first point of each frame structure with zero

coordinates, and then the reminder points coordinates are calculated from the previous point coordinates with the two fields "ElementDx", "ElementDy" in the element angles table as shown in Fig. 6.

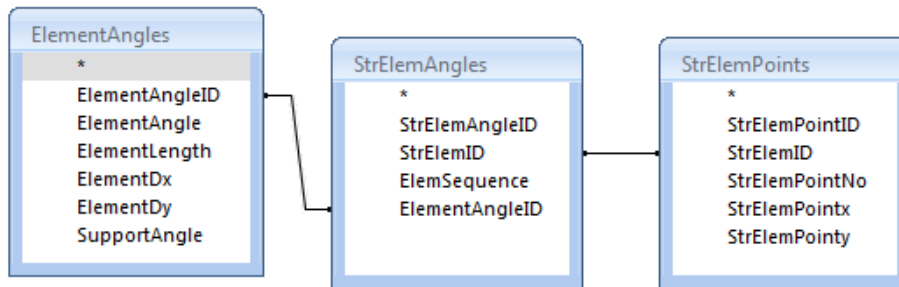


Figure 6: Filling frame points table with data

3.2 Adding Supports

Now, the main frames are ready to add supports to them. Table 7 shows support type table which

listed the types of supports as names only. In this table, four values are stored as shown in Table 8.

Table 7: Support type table structure

#	Filed Name	Field Type	
1	SupportTypeID	Long Integer	Identified number for support type
2	SupportTypeName	Text	Name of the support type

Table 8: Data stored in support type table

Support Type ID	Support Type Name
1	Fixed
2	Hing
3	Roller in X
4	Roller in Y

This table stores only the names of the supports. It is required to decide the reactions in each type of supports. The reactions in the supports are as the joint

loads. Then a table of main joint loads is constructed with the structure shown in Table 9.

Table 9: Main joint load table structure

#	Filed Name	Field Type	Field description
1	MainJointLoadID	Long Integer	Identified number for main joint load
2	LoadName	Text	Name of the main joint load
3	DefaultValue	Double	Default value of the main load
4	Dx	Double	Unit vector in x-direction
5	Dy	Double	Unit vector in y-direction
6	Mi	Double	Unit vector for rotation

This table would be used two times, in the support reactions and when it is required to load the

frames with joint loads. The values in this table are shown in Table 10.

Table 10: Data stored in main joint load table

MainJointLoadID	LoadName	DefaultValue	Dx	Dy	Mi
1	Horizontal Force	1	1	0	0
2	Vertical Force	1	0	1	0
3	Concentrated Moment	4	0	0	1

The "DefaultValue" field in this table is used when joint loads are added to the frame, and "Dx", "Dy" and "Mi" are the unit vector for each load type.

It is important to decide which type of joint loads is suitable for the support type. Then a table of support main reaction is constructed as shown in Table 11.

Table 11: Support main reaction table structure

#	Filed Name	Field Type	Field description
1	SupportMainReactionID	Long Integer	Auto-increment number
2	SupportTypeID	Long Integer	Identified number for support type
3	MainJointLoadID	Long Integer	Identified number for main joint load

The values of the data stored in this table are shown in Table 12. It is shown that the support type 1, which means fixed support, has three records because it has three reactions in the translational x and y and in the rotation directions. The hinged

support (support type 2) has two translational (x and y reactions) and the roller support (support type 3 and 4) has one reaction in the direction perpendicular to the movement direction.

Table 12: Data stored in support main reaction table

SupportMainReactionID	SupportTypeID	MainJointLoadID
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	3	2
7	4	1

Now, it is time to add the supports to the frame structures. It is noticed that for the frame to be determinate, it is provided with single fixed support at the start or the end point, or it is provided with two supports at any two different points on the frame. One of the two supports must be hinge and the other is roller in x or in y direction, or it is provided with

three roller supports at three different points but one of these three rollers must be different in direction compared to the other two supports to avoid parallel reactions.

To perform this task, a table of Structure Element with Supports "StrElemSupports" was constructed as shown in Table 13.

Table 13: Structure element with supports table structure

#	Filed Name	Field Type	Field description
1	ID	Long Integer	Auto increment number
2	StrElemSupportID	Long Integer	Identified number for the frame shape with supports
3	StrElemID	Long Integer	Identified number for the frame shape
4	StrElemPointNo	Long Integer	Number of supported point
5	SupportTypeID	Long Integer	Identified number for support type

It is noticed that the main frame structure will generate many frames with the same shape but with different types of supports. Then an identified

number for this frame is defined and stored in the "StrElemSupportID" Field.

To fill this table a temporary table named "TT2" was constructed with the structure shown in Table 14.

Table 14: Temporary table TT2 structure

#	Filed Name	Field Type	Field description
1	StrElemSupportID	Long Integer	Identified number for the frame shape with supports
2	StrElemID	Long Integer	Identified number for the frame shape
3	StrElemPointNo1	Long Integer	Point number of first support
4	SupportTypeID1	Long Integer	Type of first support
5	StrElemPointNo2	Long Integer	Point number of second support
6	SupportTypeID2	Long Integer	Type of second support
7	StrElemPointNo3	Long Integer	Point number of third support
8	SupportTypeID3	Long Integer	Type of third support
9	StrElemSupportTypeID	Long Integer	Type of supporting system

The filling of support data is made in three steps. The first step when putting a fixed support at the points with sequence one (the start point in the frame structure) or putting a fixed support at the points with sequence equal the number of elements plus one (the end point in the frame structure). The second step when putting a hinged support at any point and a roller support at a different point by making a relation between the frame points table and

themselves when the two points are different as shown in Fig. 7.

The third step when putting roller supports at any three different points by making a relation between the frame points table and themselves triple times when the three points are different as shown in Fig. 8.

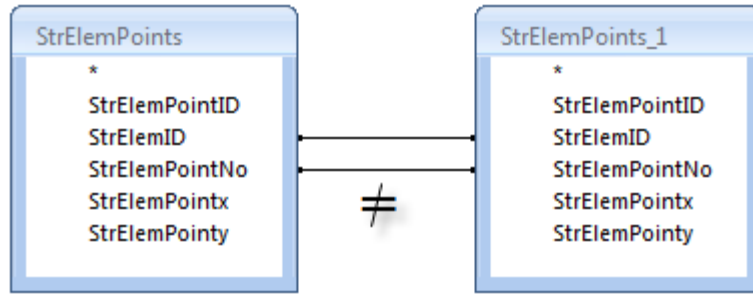


Figure 7: Filling temporary table TT2 table with data in second case

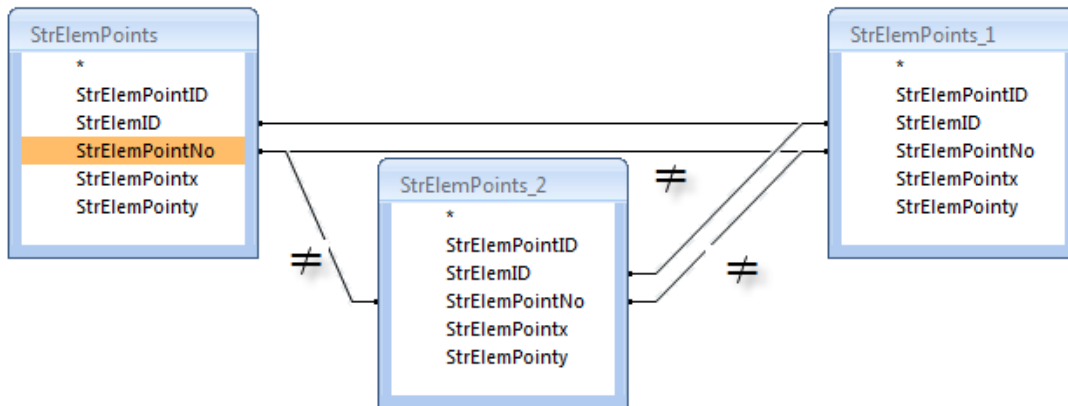


Figure 8. Filling temporary table TT2 table with data in third case

The number of the previous step is stored in the "StrElemSupportTypeID" field to be used later.

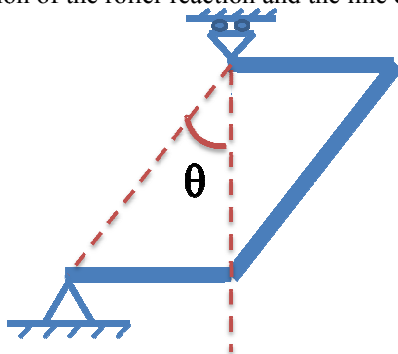
3.3 Check Structure Stability

After filling the support data, it is required to filter these data to delete the unstable structures (structures that have supports and their reactions concurrent for the second and third categories).

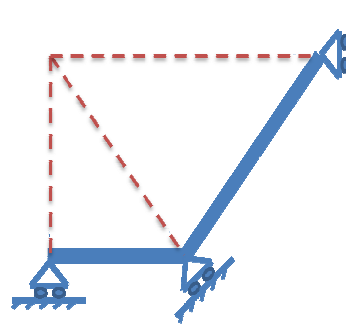
To check the intersection of the reactions in case of hinged-roller frames, the angle between the direction of the roller reaction and the line connecting

the two reaction points is obtained as shown in Fig. 9a. If this angle is zero, then the reactions are intersecting in one point, then it is an unstable frame and must be deleted from the problems stock. To check the intersection of the reactions in case of three roller frame, the intersection points of each two reactions are obtained and compared as shown in Fig. 9b.

The coordinates of the intersection point of two lines shown in Fig. 10 are given by equations 1 and 2.



(a) Hinged-roller frame



(b) Three roller frame

Figure 9. Intersection check of reactions.

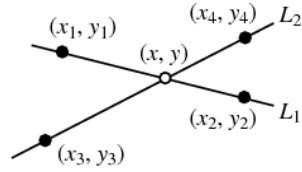


Figure 10. Intersection of two lines.

$$x = \frac{\begin{vmatrix} x_1 & y_1 \\ x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \end{vmatrix} \begin{matrix} x_1 - x_2 \\ x_3 - x_4 \end{matrix}}{\begin{vmatrix} x_1 - x_2 & y_1 - y_2 \\ x_3 - x_4 & y_3 - y_4 \end{vmatrix}} \quad (1)$$

$$y = \frac{\begin{vmatrix} x_1 & y_1 \\ x_2 & y_2 \\ x_3 & y_3 \\ x_4 & y_4 \end{vmatrix} \begin{matrix} y_1 - y_2 \\ y_3 - y_4 \end{matrix}}{\begin{vmatrix} x_1 - x_2 & y_1 - y_2 \\ x_3 - x_4 & y_3 - y_4 \end{vmatrix}} \quad (2)$$

The reactions are not given by two points on the line of action, but they are given by point of reaction and the unit vector of the reaction direction. If the points of supports are (x_1, y_1) , (x_2, y_2) and (x_3, y_3) and the unit vectors of the reactions directions are (u_1, v_1) , (u_2, v_2) and (u_3, v_3) , then the coordinates of

the intersection points of the first and second reactions are given by Equation 3 and the coordinates of the intersection points of the first and third reactions are given by Equation 4. If the intersected points are coincided, then the frame is unstable and must be deleted from the problem stock.

$$x_{12} = \frac{x_2 u_1 v_2 - x_1 u_2 v_1 + u_1 u_2 (y_1 - y_2)}{u_1 v_2 - u_2 v_1} \quad (3)$$

$$y_{12} = \frac{v_1 v_2 (x_2 - x_1) + y_1 u_1 v_2 - y_2 u_2 v_1}{u_1 v_2 - u_2 v_1}$$

$$x_{13} = \frac{x_3 u_1 v_3 - x_1 u_3 v_1 + u_1 u_3 (y_1 - y_3)}{u_1 v_3 - u_3 v_1} \quad (4)$$

$$y_{13} = \frac{v_1 v_3 (x_3 - x_1) + y_1 u_1 v_3 - y_3 u_3 v_1}{u_1 v_3 - u_3 v_1}$$

3.4 Loading

The last step of generating problems is putting joint forces on the joints in a table called "StrElemSupportLoads" with structure shown in Table 15. The field called "StrElemSupportLoadID" is the identifier of the frame structure problem with supports and loads. The structure with supports is loaded mutually on different points with joint loads that were stated in "MainJointLoad" table. The field "LoadDirectionFlag" means the direction of the load. It takes two values, one or minus one for loads in the positive or negative directions respectively.

Table 15: Frame loads table structure

#	Filed Name	Field Type	Field description
1	ID	Long Integer	Auto increment number
2	StrElemSupportLoadID	Long Integer	Identified number for the frame shape with supports and loads
3	StrElemSupportID	Long Integer	Identified number for the frame shape with supports
4	StrElemPointNo	Long Integer	Number of loaded joint
5	MainJointLoadID	Long Integer	Identified number for main joint load
6	LoadDirectionFlag	Integer	Direction of load sign

After filling this table, it is required to delete the problems that the load faces a reaction of support in the same direction as shown in Fig. 11. This is obtained when the tables "StrElemSupportLoads",

"StrElemSupports" and "SupportMainReactions" are connected as presented in Fig. 12 and the resulting records are deleted.

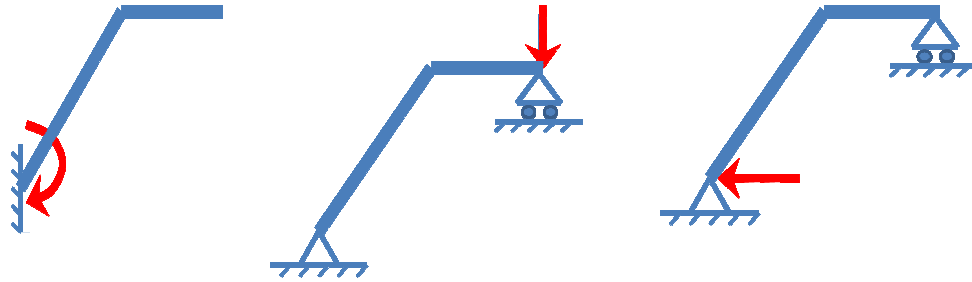


Figure 11: Un-proper supported frame with loads

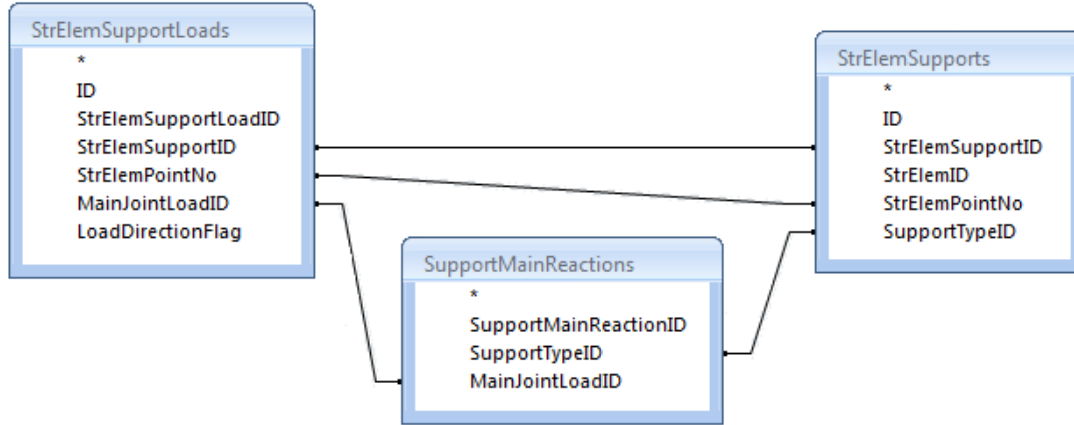


Figure 12: Connection of un-proper supported frame with loads

Applying the previous procedures on many cases of number of elements, a huge number of problems are generated. Table 16 shows the number of generated problems for each case of element numbers.

Table 16 : Number of generated problems

Element Number	Problem Numbers
1	144
2	7,296
3	124,344
4	1,296,384

4. Conclusions:

This research opens the way on the generation of huge number of problems in elementary structural analysis, which have a high benefit in learning and assessment students. The paper presented the structure of a proposed smart system that can be used to generate more than 1 million different frame problems based on simple element, support and load types. This paper shows how to convert the ideas that are stored in the professor brain into a database rules. This is the first step in a research project concerned with enhancing the structural engineering education. Other parts of the project involve developing detailed solution for the developed problems.

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