A DESIGN ALGORITHM TO CALCULATE THE STATIC
1 STIFFNESS OF THE MULTI - BOLTED JOINT.

2 PART II: JOINT DESIGN ALGORITHM .

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4 ABSTRACT

To day designers of the machine tools requires acceptable and simple methods or tools which enable to achieve their works in minimum time and less effort. Therefore, this work is concerned with establishment of a design algorithms to calculate the value of the static stiffness of a fixed joint based on the multi-bolted joint. This model has been developed in the first part of this paper. Based on the elements of this model will be deciding the proper algorithm which can be used to calculate the static stiffness values. The comparison of calculated and experimental results is also given. The proposed design algorithm and its computer program are now available to the designers.

INTRODUCTION

The precision of the machine tools are defined by both rigidity of the parts of machine tool structure and joint stiffness. Joints in machine tools accept complex loading and are loaded by overturning (bending) moment too. Joint deflection in machine tools derive mutual inclination of the contacting coupled elements. Owing to these inclinations there appeares elastic displacement of the cutting parts of the tools which are much greater than those in the joint interface . Therefore, the principal design criteria of the fixed joints are stiffness and damping.

There are many publications of both fundamental and experimental nature which are concerned with the design parameters affecting the characteristics of the fixed joints [1-2-3-4-5-6] The basic work in these investigations are that modelling and testing of simple joint constructions to derive some experimental and theoritical relations. A totally reliable

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mathematical models to evaluate the stiffness of the multi-bolted joint have been recently developed.In this work a proper design algorithm has been constructed based on the element of the multi-bolted joint.The exactness of the calculated values are checked with the experimental data[4-7] The computer program of the constructed design algorithm has been carried out on computer KRS-4200.

DESCRIPTION OF THE PROPOSED DESIGN ALGORITHM.

Fig.1 represents the flow chart of the elements of the design algorithm.In the following are the discrption of the main algorithm in details :

1- Data collection of the joint to be analysed.
These data can be summerized in the following items:

- the main dimensions of the flange(See Fig.2). h_{f1} ,h_{f2}, e_1 and e_2 .
- number of tightening bolts to be used n and its basis coordinate X_{oi} , Y_{oi} .
- material to be used for the bolts and flange. E_s , E_{f1}, E_{f2} , FM and $\sigma_{zul.}$.
- surface quality factors α and m .
- dimensions of the tightning bolts to be used d_s , A_s , and P .
- the needed load factor V .
- the bolt preload F_V .
- the external loads on the joint interface F_X , F_Y , F_Z , M_X , M_Y , and M_Z (See Fig. 3)

2- Checking the static joint safety stresses.
The correct judgement of the maximum joint stresses may be decided by checking the high loaded bolt in the joint.This bolt may be defined as a bolt which has the maximum lot of the external loads affecting the joint interface $F_{B\ max.}$ By this load and the load factor V could be recheck of the minimum cross section of the fastining bolt to be used .The calculatoins are also made to the final checking of joint safety stresses $\sigma_{zul.}$, $\sigma_{z\ max.}$ and $\sigma_{ver.}$ (See Fig. 1)

3-Determination of the static stiffness of each bolt in the joint.
According to the lot of each bolt in the joint from the external loads the static stiffness can be calculated by an iteration cycle.It can be summerized in the following steps : (See Fig. 1)

- calculation the resultant force on the flange or the members to be jointed (F_R)
- due to the linearization of the resultant force it can be calculate the static stiffness of the members to be jointed (C_V)
- the value of the non-linearized spring constant C_V is to be used for calculate the actual resultant force R_R .

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- calculation the non-linear static stiffness C_{V2} .
- the limit of convergence of the iteration process has to be in the region $0 < I.C.L \leq$ about 1 % .
- the iteration process is considered to be converged when the approximate solution for the static stiffness of the members came into the mentioned convergence limit .

4- Determination of the location of the centroid point S and the main coordinates of the joint X_S , Y_S and φ_S

5- calculation of the static joint stiffness .
C_X , C_Y , C_Z , $C_{\varphi X}$, $C_{\varphi Y}$, and $C_{\varphi Z}$.

6- Summary of the results. They are :
- diameter of the bolt to be used d_S .
- number of bolts to be used n .
- elasticity modelus of bolt material E_S .
- coordinates of each bolt in the joint X_{ni} , Y_{ni} .
- the bolt preload F_V .
- the values of the external loads F_X, F_Y, F_Z, M_X, M_Y and M_Z .
- the factors of the joint surface quality α , m .
- the calculated static joint stiffness .
C_X , C_Y , C_Z , $C_{\varphi X}$, $C_{\varphi Y}$ and $C_{\varphi Z}$.

EXACTNESS OF THE DESIGN ALGORITHM

The exactness of the design algorithms calculations may be checked by the comparison of the theoritical values and the experimental results.Becouse the stiffness value of a single bolted joint is usually affected with its external force it can be compared between the calculated and experimental values of both the external force F_B and the normal deflection of each bolt in the joint. In this field the main experimental data have been developed by SCHULZ [7] on the physical model of machine culumn and IŻYKOWSKI [4] .

In the following are the discussion of the comarison between the experimental and theoritical results :

a- THE COMPARISON WITH SCHULZ'S EXPERIMENT

The analysis of the static behaviour of a multi-bolted joint has been developed by SCHULZ [7] on the column of the milling machine.This culumn has been fabricated from the steel sheets by the electric welding process with the original dimensions.Fig. 4 shows the main dimensions of the experimental machine culumn .The aims of the experiment ware : Investigation of the effect of the values and directions of the external loads and the needed joint preload F_V on the joint deflection behaviour. It has been developed by the preloads 10 , 20 and 30 KN for each bolt and the total external force (affected on the culumn in Z- direction) 5,10 and 15 KN . Fig. 5 illustrate the experimental and theoritical variation of the external load on each bolt either in the tension and comperision side of the joint.It is clear that, the maximum deflection values were as in the tension side also in the comprision side of the joint .The deviation between the experimental and theoritical values are not exceed than 5 %

Fig. 6 shows the experimental and calculated deflection of the maximum loaded bolt in the tension side of the joint.Also,the external load was affecting in Z-direction. The tendenz of the curves show a progressiv increase of the deflection values with the rise of the external load F_Z .

It is clear also that the difference between the experimental and the theoritical values are very small specially at high joint preload.

b- THE COMPARISON WITH IŻYKOWSKI'S EXPERIMENT

The IŻYKOWSKI'S experiment [4] has been carried out to study the static deformation behaviour of four types of culumn models.The models were fabricated by welding process.Fig. 7- a shows the structure model 1-C which is fastened with the base by 12 bolts M8 .The base was manufactured from steel 45 with dimensions 500 x 500 x 100 mm.The quality of the two contact surfaces was hand scraped(3 Spots/ cm^2) for the base.The bolts were tightened with a preload 10 ;12.5 and 15 KN.

The external load in X- direction was 30 KN. Fig. 7 shows the comparison between the theoritical and experimental values of the excess load in the bolt F_{sz} due to the external load.It is clear that the calculated values of F_{sz} are to agree with the experimental results either in tension or comprision side . This meant also that the calculations of the design algorithm can be accepted .

CONCLUSION

The technical progress and development of the machine tools enables designers,manufactures,users of machine tools to aims at over incensing qualtative and quantative efficiency of their machines .

This paper present a powerfull design algorithm which can used to calculate the static joint stiffness is established . The algorithm considered the design parameters of the multi-bolted joint. A computer program ware built to calculat the values of the static joint stiffness.

NOMEMCLATURE

A_K Contact area (mm.^{2})

A_S Tensile stress area of screw bolt (mm.^{2})

C_2 Stiffness of the bolt under external load (N/ μm.)

C_3 Stiffness of the members to be jointed under external load (N/ μm.)

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C_{sv}	Single- bolted joint stiffness (N/ μm.)
C_X	Static shear stiffness of the multi-bolted joint in X-direction (N/ μm.)
C_Y	Static shear stiffness of the multi-bolted joint in Y-direction (N/ μm.)
C_Z	Static tension stiffness of the multi-bolted joint in Z-direction (N/ μm.)
$C_{\varphi x}$	Static turnover stiffness about X-direction(N.m/μrad)
$C_{\varphi y}$	Static turnover stiffness about Y-direction(N.m/μrad)
$C_{\varphi z}$	Static torsion stiffness(N.m/μrad)
d_s	Major bolt diameter(mm.)
E_s	Modulus of elasticity of the material($N/mm.^2$)
E_f	Modulus of elasticity of the flange material($N/mm.^2$)
H_f	Flange height(mm.)
F_B	External tension load (N)
F_V	Preload on bolt due to tighenning(N)
FM	Max. elastic tension force of the bolt material(N)
F_R	Resultant load on the members to be jointed (N)
$F_{X,Y,Z}$	Forces acting on the joint in X-,Y- and Z-direction(N)
$M_{X,Y,Z}$	Moments acting on the joint about X-, Y- and Z- direction (N.m)
n	Number of bolts in the joint
R	Constant after KIRSANOVA ($mm.^2/\sqrt{N}$)
P	Pitch of the thread (mm.)
S	Centeroid point of the multi-bolted joint.
V	Load factor
X,Y,Z	Main joint coordinates.
X_o,Y_o,Z_o	Basis joint coordinates.
X_n,Y_n,Z_n	Neutral joint coordinates.
X_i,Y_i	Coordinates of the bolt i in the joint w.r.t the main coordinates.
X_{oi},Y_{oi}	Coordinates of the bolt i in the joint w.r.t the basis coordinates.
$X_{ni}.Y_{ni}$	Coordinates of the bolt i in the joint w.r.t the neutral coordinates.
φ_s	Rotation angle of the main joint coordinates(Grad)
α,m	Constants.

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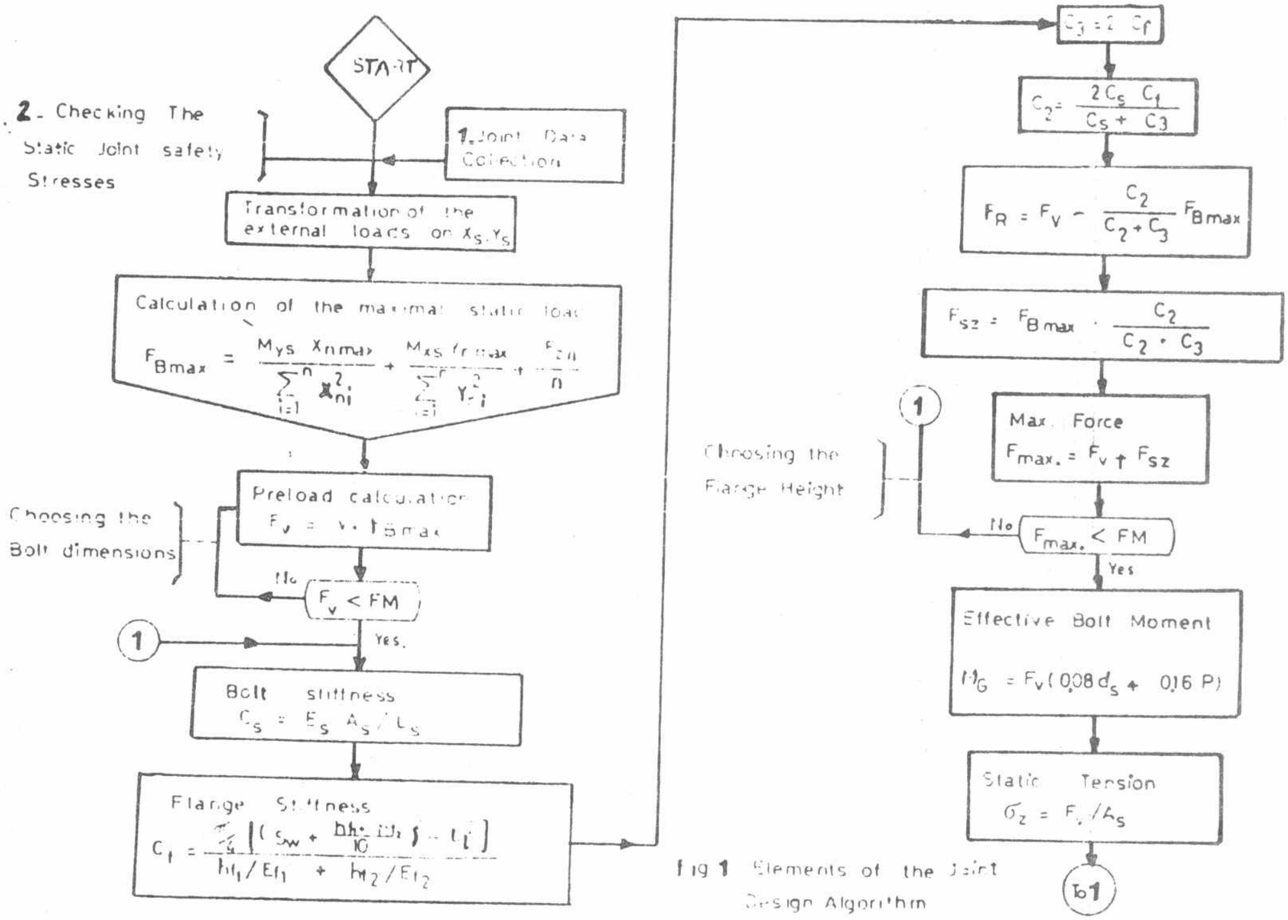

Fig 1 Elements of the Joint Design Algorithm

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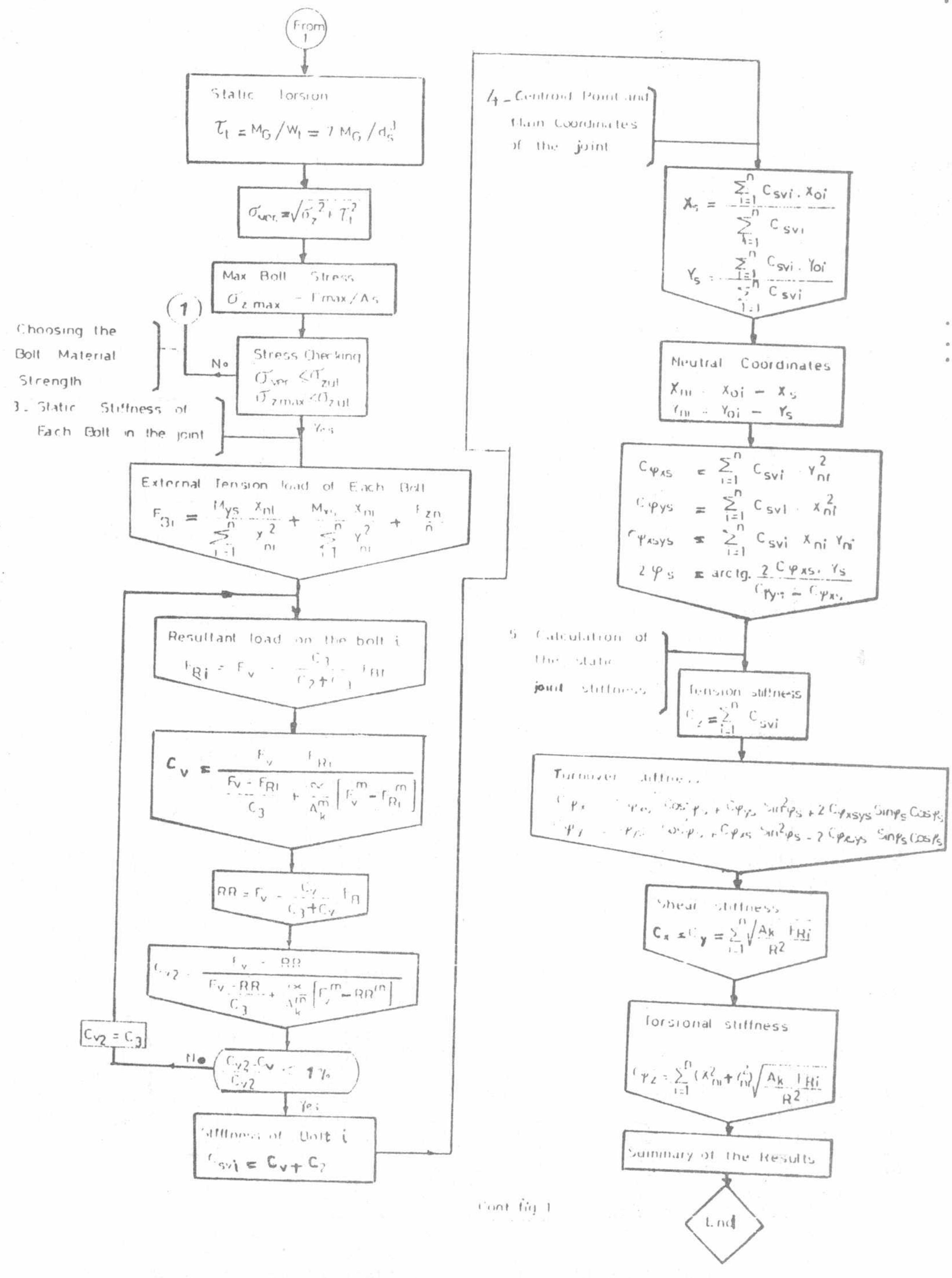
From 1
Static Torsion
Max Bolt Stress
Choosing the Bolt Material Strength
Stress Checking
No
Yes
3. Static Stiffness of Each Bolt in the joint
External Tension load of Each Bolt
Resultant load on the bolt i
$C_{v2} = C_3$
No
Yes
Stiffness of Unit i
$C_{svi} = C_v + C_2$
4 - Centroid Point and Main Coordinates of the joint
Neutral Coordinates
5 Calculation of the static joint stiffness
Tension stiffness
Turnover stiffness
Shear stiffness
Torsional stiffness
Summary of the Results
End

Cont fig 1

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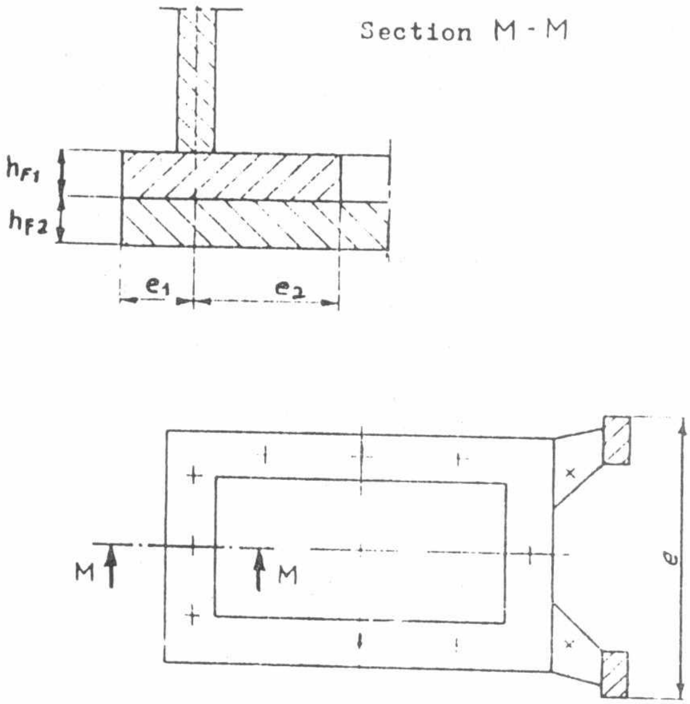


Fig.(2) Construction and dimensions of the flange.

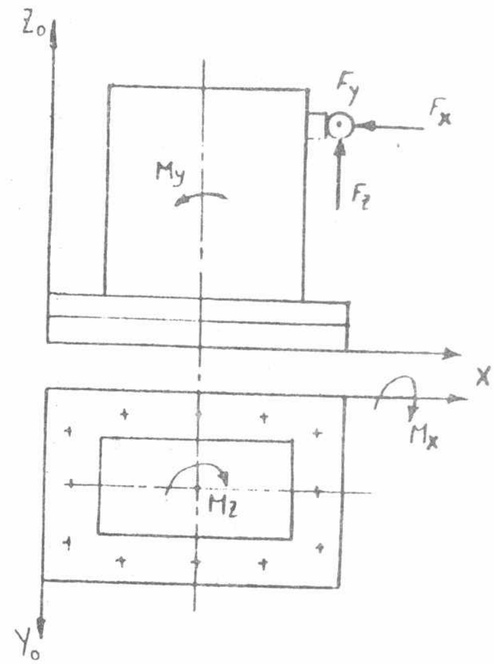


Fig.(3) Loading of the joint.

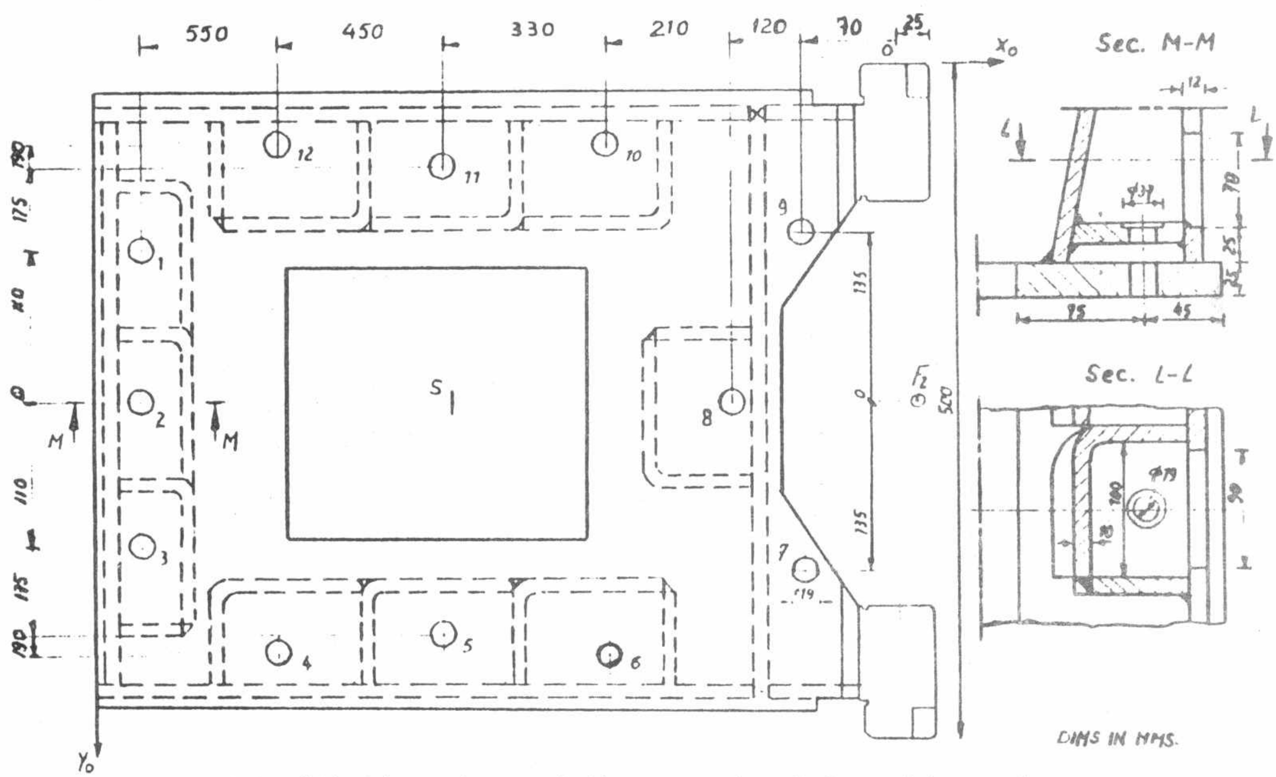
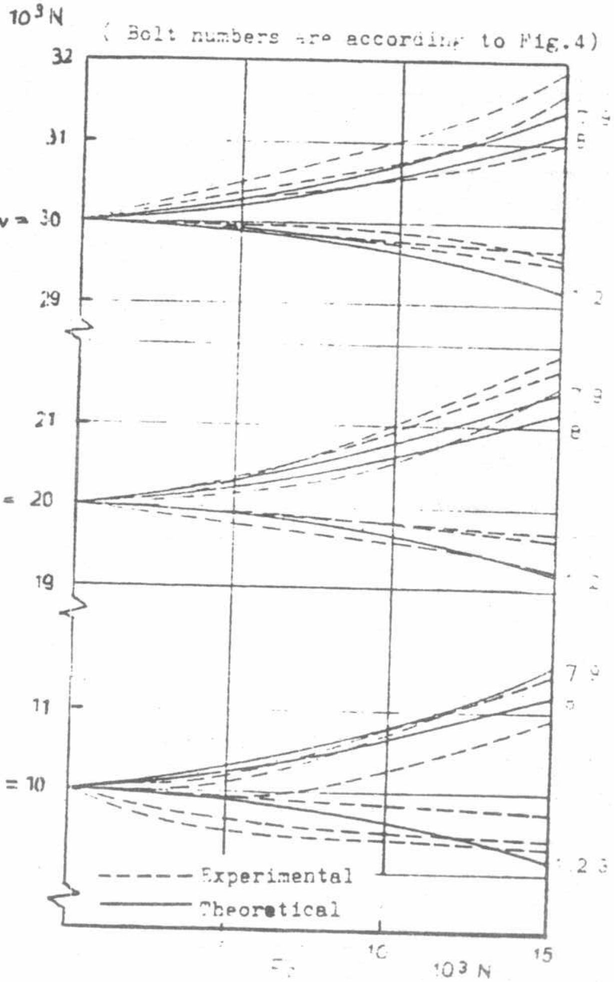
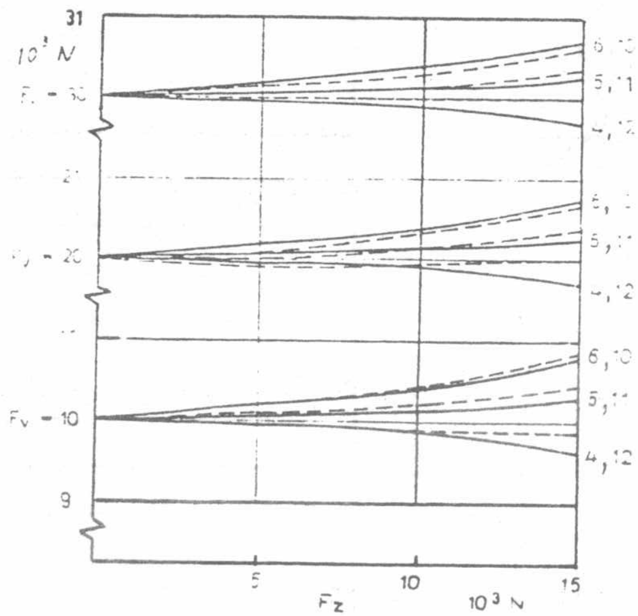


Fig.(4) Dimensions of the experimental machine culumn by SCHULZ [7] .





F.(5) Comparison of the theoretical results with the experimental data of Schulz's experiment [7].

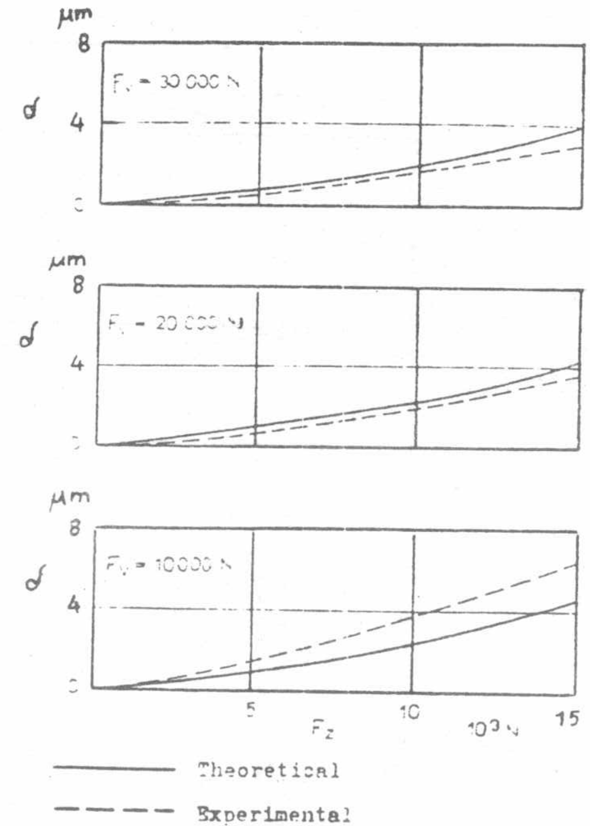
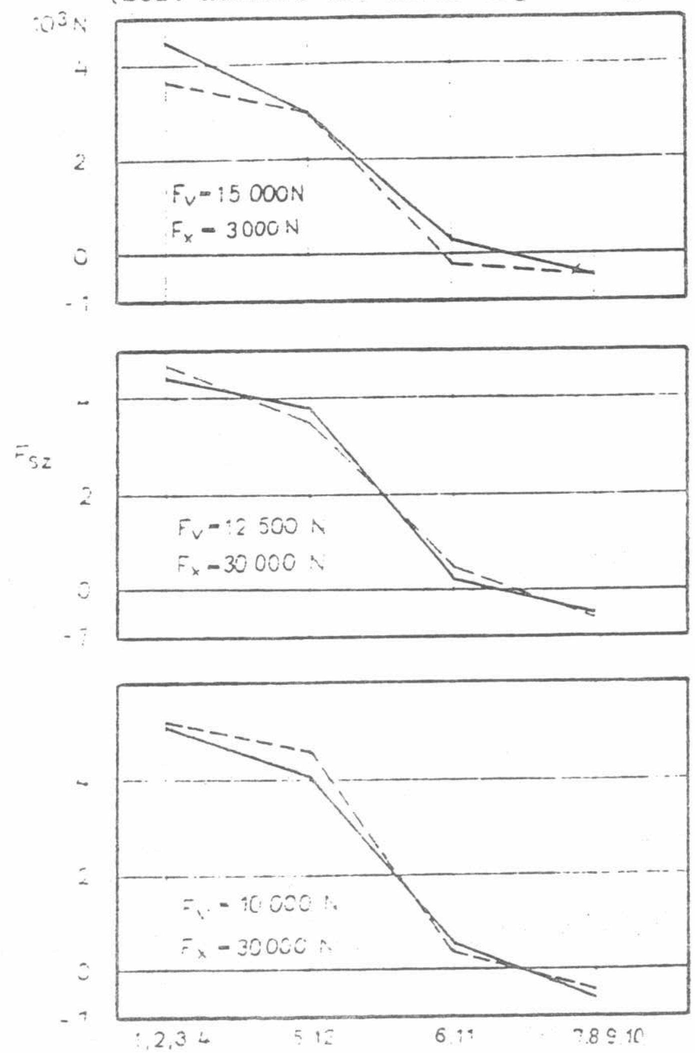


Fig.(6) Comparison of experimental and calculated deflection.

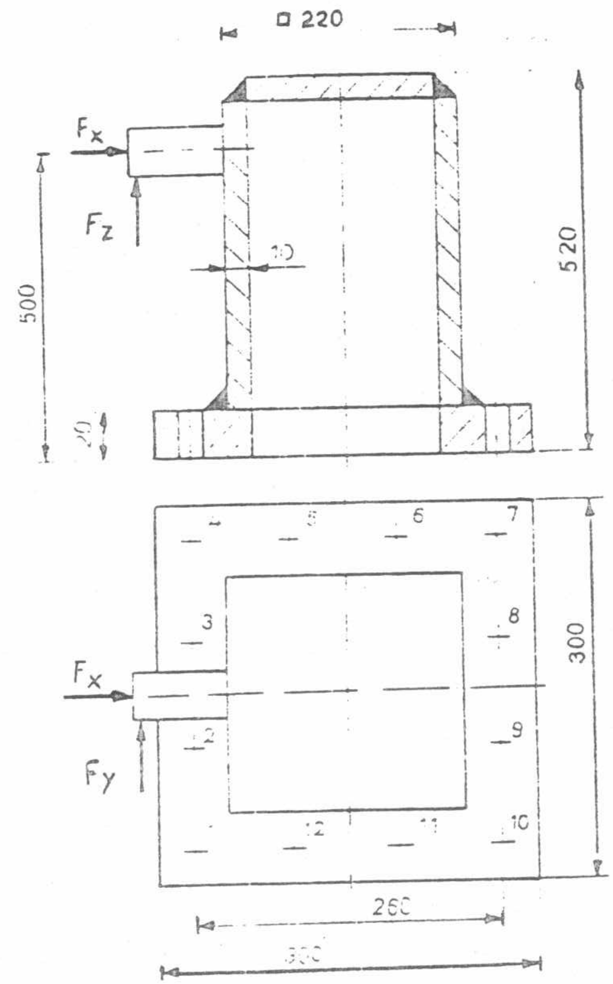
(Bolt numbers are according to Fig. 7-a)



——— Theoretical

– – – – Experimental

Fig.(7) Comparison of the theoretical results with Iźykowski experiment [4] .



DIMS. in mm

Ds = 8 mm , n = 12 Bolts. ; Fx = 30 000 N

Fig. (7-a)