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CORE LOADED THIN-WALLED SLEEVED COLUMN SYSTEM

By

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INTRODUCTION

In conventional columns, the load carrying capacity is governed by the yield strength of the material and its buckling strength. The yield strength of the compression member is governed by the mechanical property of the material and its area of cross section while its elastic buckling strength depends on the least flexural stiffness (EI) of the cross section and its effective unsupported length. The elastic flexural buckling strength of a compression member is given by the well known Euler equation. In practice the strength of conventional compression members is less than both the yield strength and Euler buckling strength due to the effects of imperfections, residual stresses etc.(Bjorhovde(1988)). In this paper behaviour of a novel patented concept, referred to as core loaded thin-walled sleeved column system, is discussed.

CONVENTIONAL COMPRESSION MEMBERS

In the case of conventional compression members, the flexural stiffness (EI) and the axial strength are provided by the same section. Usually the use of higher strength steel, (which has a lower cost/to strength ratio) would lead to an economical design only if the material strength can be fully utilized. In conventional compression members, the use of a high strength material leads to a smaller cross sectional area. This area cannot be distributed appropriately to obtain the necessary flexural stiffness, required from the buckling strength consideration. Consequently, the economy associated with the high strength steel cannot be fully exploited in conventional compression members.

Tubular sections are frequently used for compression members. They may fail by barrel shaped wall buckling, diamond shaped local buckling or overall buckling. The type of failure of a circular tubular compression member depends upon the factor, Z, defined as (AISI (1988)).

$$Z = 0.954L/Rt \tag{1}$$

Where R is the mean radius, t is the wall thickness, L is the effective length of the tubular member. When $Z \leq 2.85$ the wall plate undergoes barrel type of buckling at the stress of

$$\sigma_{cr1} = \pi^2 Et^2/(12\,(1-\mu^2)L^2) \tag{2}$$

When $2.85 \leq Z \leq 50$, the local buckling in the diamond shapes occurs at the stress of

$$\sigma_{cr2} = 0.605\ Et/R \tag{3}$$

When $Z > 50$ the overall buckling failure at the Euler stress given below occurs

$$\sigma_{cr3} = \pi^2 E/(8(R/L)^2) \tag{4}$$

These buckling, assumed to occur in the elastic range, get modified due to imperfections, residual stresses and inelastic material behaviour.

Concrete infilled tabular columns are also used in practice. The main purpose of this system - is to efficiently utilize the best properties of both concrete and steel. It has been shown that before failure under compression of such composite columns, the compressive strength of concrete in the longitudinal direction is increased due to the confining effect of steel shell on concrete and the consequent triaxial state of stress in the concrete. Loading of the concrete infill alone, both the concrete infill and the shell, as well as the shell alone has been studied by Ramamurthy et al. (1990). In the composite system, loading of the circular shell in the axial direction can not be avoided and hence the composite compression members suffer from the effects of the residual stresses and imperfections as the conventional steel columns.

SLEEVED COLUMN SYSTEM

Core loaded sleeved column system is an innovative patented concept, wherein the resistance to the axial force without yielding and flexural buckling, both of which are conventionally provided by the same member, are disassociated. The system consists of a core placed inside the sleeve with a small gap between the core and the sleeve, so that no axial load is transferred from the axially loaded core to the sleeve. Only the core is designed to carry the full axial load at its yield strength, while the sleeve is designed as an element to resist the lateral buckling under axial compression. Hence, the axially loaded core behaves as a compression member with continuous lateral support given by the sleeve. Thus even discontinuous core pieces could be used to support the axial compressive load efficiently. Further, very high strength steel could be efficiently and economically utilised in the core. Since the sleeve does not experience any externally applied axial load, the actual buckling strength of the sleeve is as high as the Euler strength and is not affected by effects of the residual stresses, local buckling and inelasticity.

Sridhara and Ramaswamy (1982) reported the behaviour of a core inside a sleeve. Raju (1987) and Kumar (1988), have reported tests confirming the behaviour of a core within a very stiff sleeve. Prasad (1989) has used a core rod loaded axially within a plexiglass sleeve, to study and photograph the core as it deforms in an increasingly higher buckling mode shape with increase in the axial force. Tests carried out at the University of Austria (Sridhara (1988)) have led to the conclusion that the sleeved column system is not advantageous for slender columns.

A systematic evaluation and development of the sleeved column system and its applications have been underway at the Structural Engineering Laboratory, the Indian Institute of Technology - Madras, with the support of the Tube Investments (India) Ltd., co-owner of the patented system. Kalyanaraman et al (1994) have presented the behaviour and the economy of the core loaded sleeved column system for the various ranges of the slenderness ratio of the system and the diameter to thickness ratio of the sleeve. In their study, it was shown that the full yield strength of even the high strength core rods could be reached as long as the sleeve is not subjected to a high axial compression and has the Euler buckling strength greater than or equal to the core strength. They have in addition shown that the sleeved column systems are most economical for the lower values of the slenderness ratio ($l/r < 75$) and the larger diameter to thickness ratio ranges. Hence an investigation has been carried out to study the behaviour of the core loaded thin-walled sleeved column system, which is presented in this paper.

It is well known that the elastic flexural buckling strength of a tubular compression member increases with increase in the radius (Eq.4), whereas its local buckling strength decreases as the radius is increased (Eq.3). In the core loaded sleeved column system, since the axial force is not applied on the sleeve, only the flexure buckling strength of the sleeve and not the local buckling strength, is of consequence. Hence, the increase in the efficiency of thin-walled tubular members with a large diameter to thickness ratio,(D/t), can be exploited in the core loaded system.The main aim of this work is to evaluate the behaviour of the core loaded sleeved column system with a thin- walled sleeve. This paper presents the details and the results of an experimental study on the behaviour of the core loaded thin-walled sleeved column system, having larger D/t ratios (in the range of 100 to 200).

EXPERIMENTAL INVESTIGATION

In the core loaded system, the axial compressive force is directly applied to the core and no axial load is applied on the sleeve. Fig.1 illustrates a typical sample of a core loaded system tested. As the sleeve does not carry any axial load, the presence of imperfections, residual stresses, etc. in the sleeve does not adversely affect the flexural buckling strength of the system. Hence, loads closer to the Euler buckling load of the sleeve can be carried by the system with L/r even in the range of 25 to 70 and D/t in the range of 100 to 200. A series of experiments were carried out to study the behaviour of such core loaded thin-walled sleeved column system.

Design Of Specimens

The following parameters are considered while designing the specimens for the experimental study.

Diameter to thickness ratio (D/t) = 100, 160, 200

Slenderness ratio of the sleeve (l/r) = 30, 50, 70.

Altogether nine specimens have been designed for the combination of these parameters.

The maximum length of the specimen that can be accommodated (6m) and the capacity of the testing machine (600 tonne) were the main constraints in the design of the specimen. Considering these and the ease of production of the specimen, the inner diameter of the sleeve was fixed as 200 mm. The sleeve thickness of 1.0, 1.25 and 2.0 mm were chosen based on the standard sheets. The Euler buckling strength of the sleeve P_e was calculated for the specimen chosen. The number of core rods, N_c required to carry the load corresponding to the Euler buckling was designed using the equation

$$N_c = P_e/(F_{yc} A_{c1}) \tag{5}$$

where F_{yc} and A_{c1} are the yield strength and the area of one core rod, respectively. 8 mm high tensile prestressing wires were used for core rods. Table 1 gives the details of the specimens tested so far.

Fabrication

As the standard pipe sections of the size designed are not available in the market, the large diameter thin-walled sleeves were formed by cold rolling mild steel sheets into circular pipes. The TIG welding was chosen for the meridional seams to reduce the heat generated in the process and the consequent distortion.

The HT steel wire for the core were ground to the required exact length. In order to prevent the rods from moving out of position, while the space between the core and the sleeve was grouted, washers were used. A 2 mm thick circular mild steel plate, with holes drilled in it corresponding to the exact layout of the core wires is termed as a washer. The washers along with the HT wires were held in position by forming a cage. The cage was covered uniformly with a viscous oil before concreting in order to break the bond between the core and the concrete. The cage is inserted into the sleeve before grouting. The washers ensured the straightness of the core before grouting. The concrete was used as a filler material between the core and the sleeve to prevent the buckling of the HT Wires, independent of the sleeve.

The compression load was transferred from the machine head to the column through loading lugs. The lugs were designed to carry the maximum axial force on sleeved column systems tested.The lugs were machined out of EN24 steel, heat treated and hardened to withstand the contact stresses as high as 1500 MPa. One face of the loading lugs was ground flat to ensure uniform contact with all the core rods. The other face of the lugs was ground cylindrically to simulate the hinged conditions at the ends of the column (Fig.1).

Experimental Set Up

Fig.2 shows the experimental set up. The column along with its end fixtures was centered in a 600 tonne testing machine and set vertical between the machine heads. Ten millimeter ST-4 strain gauges, three in the meridional direction at 120° apart and two circumferentially at the diametrically opposite points were located at the mid-length of the column. The strains were measured using a data logging system. Two dial gauges (One parallel and the other perpendicular to the end rollers) were located at the mid height of the column to measure lateral deflections at the mid-height.

Testing Procedure

The concentric loading of the specimen was ascertained by applying around 20% of the expected failure load and ensuring that the lateral deflection and the bending strains are within reasonable small limits. Subsequently, the specimen was unloaded to a small initial load before starting the actual test. The loading was applied gradually and in increments of around one tenth of the expected failure load. After every load increment, the strain gauge and the dial gauge readings were recorded.

DISCUSSION OF TEST RESULTS

Based on the strain gauge readings on the sleeve, the variation of the axial force on the sleeve with the increase in the external load was evaluated. Fig.3 shows a typical variation of the sleeve force with the increase in the external load. It was found in the earlier test specimens that inspite of efforts to debond the high strength core wires with viscous oil, the axial force in the sleeve could be as high as fifty percent of the external load. In order to improve the debonding further, grease coating of wires was used in the subsequent specimens.

This reduced the axial force transferred to the sleeve to an acceptable level. The axial stress in the sleeve subsequently was such that Euler buckling strength of the sleeve could be mobilised. Fig.4 shows the typical variation of the lateral deflection of a specimen with increase in the axial compression. It is seen that due to initial imperfections, the lateral deflection of the specimen increases from the very beginning of loading. However, as the Euler buckling load is reached, the lateral deflection increases drastically.

The failure load of the seven specimens, which have been tested so far, are presented in table 2 along with the theoretical values of the core yield strength and the sleeve Euler buckling strength. The specimen no.5 failed by the buckling of the core wires in the region of their projection beyond the filler material. The whole group of core rods failed in the torsional mode, wherein each individual core wire experienced flexural buckling, before the yielding. The specimen no. 7 failed at load below the Euler buckling strength of the sleeve, due to the excessive axial stress in the sleeve ($P_s/P=0.75$). It is seen that in all the other sleeved column specimens, the strength is nearly equal to the lower value of the Euler buckling strength of the sleeve and the yield strength of the core. This clearly indicates that in the case of thin-walled core loaded sleeved column system, the Euler buckling strength of the sleeve can be mobilised as long as the core yield strength is greater than or equal to the Euler buckling strength of the sleeve and the axial stress on the sleeve is not large enough to reach the inelastic range under the combined effect of the residual stress and the bending stress due to initial imperfections. This is true even for specimens with diameter to thickness ratio of the sleeve as high as 200.

ECONOMY OF THE SYSTEM

The relative economy of the core loaded sleeved column system (1.0-cost of core loaded systems/cost of conventional column), is compared in Fig.5 for the various values of the length of the column, the load on the column and the diameter to thickness ratio of the sleeve. The D/t ratio of conventional column is restricted to be equal to 50 in this study.

The relative cost per unit weight the high strength steel wire (σ_{yc} = 1400 MPa), the mild steel structural pipes used as sleeves (σ_{ys} = 250 MPa) and the filler concrete, was assumed to be in the ratio of 75:50:2 for this comparison. More details about the relative cost evaluation is discussed by Kalyanaraman et al. (1994).

It is seen that the core loaded system is more economical compared to the conventional steel compression members, essentially over the entire range of all the parameters considered. It is seen that generally the economy of the core loaded system is higher for the members that are shorter, heavily loaded and have larger diameter to thickness ratio.

Table 3 shows a comparison of the cost of the specimens designed for the experimental evaluation in this study and the cost of corresponding designs using conventional steel and reinforced concrete members. It is again seen that the core loaded system exhibits considerable economy in the case of shorter and heavily loaded members.

SUMMARY AND CONCLUSIONS

The experimental study on the behaviour and the strength of core loaded thin-walled sleeved column systems and the results of economic evaluation of the systems were presented.

It was shown that as long as the axial load is essentially transferred to the core designed to carry this load without yielding, the Euler buckling strength of the sleeve can be fully mobilised. Further it was seen that the core loaded thin-walled sleeved column system is more economical for shorter, heavily loaded and large D/t ratio members.

Additional work is underway to study the effects of axial compression and bending moment on the sleeve and the behaviour of core loaded systems having even larger D/t ratio and made of other materials. Application of the core loaded system to water tank towers has been already demonstrated. Its application to offshore towers, bridge towers, aerospace structures and roof space trusses are currently under study.

ACKNOWLEDGEMENT

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REFERENCES

AISI (1989) " Specification for the Design of Cold-Formed Steel Structural Members", American Iron and Steel Institute, Washington D.C.

Bjorhovde, R. (1988), ` Columns: From Theory to Practice', Engineering Journal/AISC, First Quarter, pp.21-34.

Erath, A.P. (1989), ` Analytical Study of Sleeved Columns', M.S.Report, Department of Civil Engineering, University of Arizona, Tuesin AZ.

Galambos T.K. (1993) "Guide to Stability Design Criteria for Metal Structures" The Structural Stability Research Council 4th Edition, Wiley-Interscience, Newyork, N.Y.

Jones, S.W., Kirby P.H. and Nethercot, D.A. (1983) ` Columns with Semi Rigid Joints' ASCE Journal of the Structural Division, Vol.108, No.512. pp.361-372.

Kalyanaraman V, Sridhara B.N., Mahadevan K., "Sleeved Column System", Proc. SSRC Task group meetings and Technical Sessions", 20-22, June 1994, Lehigh University, Bethlehem, PA, USA.

Kumar. N.S.(1988), ‘ Experimental Investigation on Sleeved Column Systems' M.E.Thesis, Bangalore University,Bangalore, India.

Murali Mohan Raju. M. (1987) ‘ Analysis and Behaviour of Sleeved Compression Members and Continuous Sleeved Columns', M.E.Thesis, Bangalore University, Bangalore, India.

Prasad B.K. (1989) ‘ Experimental investigation of Sleeved Column' M.S.Thesis Department of Civil Engineering, University of Arizona, Tueson.

Ramamurthy L.N., and Srinivasan C.N., (1990)," Behaviour of Concrete Infilled Tubular Columns", Proc. Advances in Steel Structures, Feb.7-9,1990 IIT-MADRAS 36, India PP.194-203.

Sridhara B.N. and Ramaswamy M.A. (1982) ‘ Sleeved Column as Compression Member' Unpublished Report, Bangalore, India.

Sridhara B.N. (1988), ‘ Report on Tests carried out at University of Austria, Vienna Unpublished Report, Bangalore, India.

TABLE 1 - DETAILS OF TEST SPECIMEN

Specimen No.	Sleeve Details					Core Details	
	Inner Dia (D) (mm)	Thickness (t) (mm.)	Effective length (L) (mm.)	D/t	L/r	Dia (mm.)	No.
1.	200	1.00	960	200	13.5	8	36
2.	200	1.00	1890	200	26.6	8	27
3.	200	1.25	2030	160	28.5	8	27
4.	200	2.00	1750	100	28.4	8	44
5.	200	1.00	3280	200	46.4	8	8
6.	200	1.25	3650	160	51.3	8	9
7.	200	2.00	3650	100	51.1	8	14

TABLE 2 - TEST RESULTS

Specimen No.	D/t	L/r	P_f (kN)	P_e (kN)	P_{yc} (kN)	P_f / P_e	P_f / P_{yc}	P_s / P_f
1	200	13.5	2714	7001	2533	0.39	1.07	0.06
2	200	26.6	1740	1806	1900	0.96	0.92	0.24
3	160	28.5	1650	1964	1900	0.84	0.87	0.54
4	100	28.4	3170	4277	3096	0.74	1.02	0.20
5	200	46.4	474	600	563	0.79	0.84	0.25
6	160	51.3	620	608	633	1.02	0.98	0.15
7	100	51.1	700	983	985	0.71	0.71	0.65

Note :		
	P_f	Experimental failure load
	P_e	Euler buckling strength
	P_{yc}	Core yield load

TABLE 3 - COST COMPARISON OF SPECIMEN TESTED

Load (kN)	Length (m)	Core Loaded System				Steel Column			Concrete column		
		D/t	D (mm)	No.	Cost (Rs/m)	D (mm)	t (mm)	Cost (Rs/m)	D (cm)	A_s (Sq cm)	Cost (Rs/m)
3225	2.00	100	200	44	537.20	300	10.86	1221.30	55.0	22.50	2055.40
2024	2.00	160	200	27	374.43	301	8.60	766.10	37.5	11.00	1008.30
1426	2.00	200	200	20	311.01	252	7.20	536.90	31.5	7.80	711.90
1027	3.60	100	200	14	329.56	225	6.40	426.20	28.0	6.20	563.10
640	3.60	160	200	9	250.04	184	5.30	288.60	21.0	3.50	316.30
511	3.60	200	200	7	221.03	168	4.80	238.60	19.0	2.80	258.90
524	5.00*	100	200	7	281.00	183	5.23	283.20	19.0	2.80	258.90
326	5.00*	160	200	5	222.15	156	4.46	205.90	15.0	1.80	161.50
261	5.00*	200	200	4	200.27	145	4.14	177.70	13.5	1.40	130.70

* Tests on specimens pending

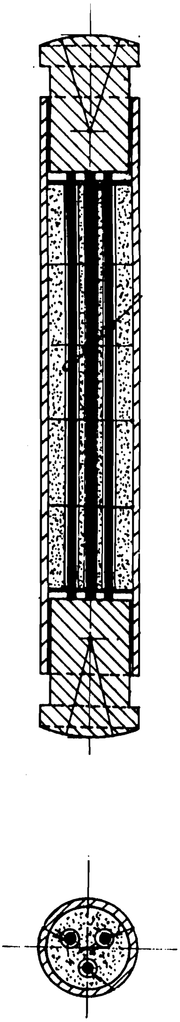

FIG.1 CORE LOADED SLEEVED COLUMN SPECIMEN

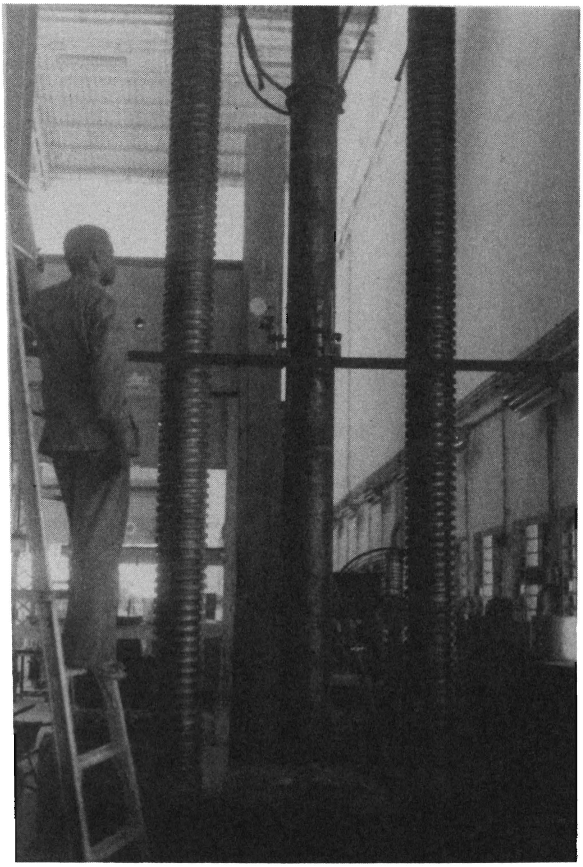

FIG.2 EXPERIMENTAL SETUP

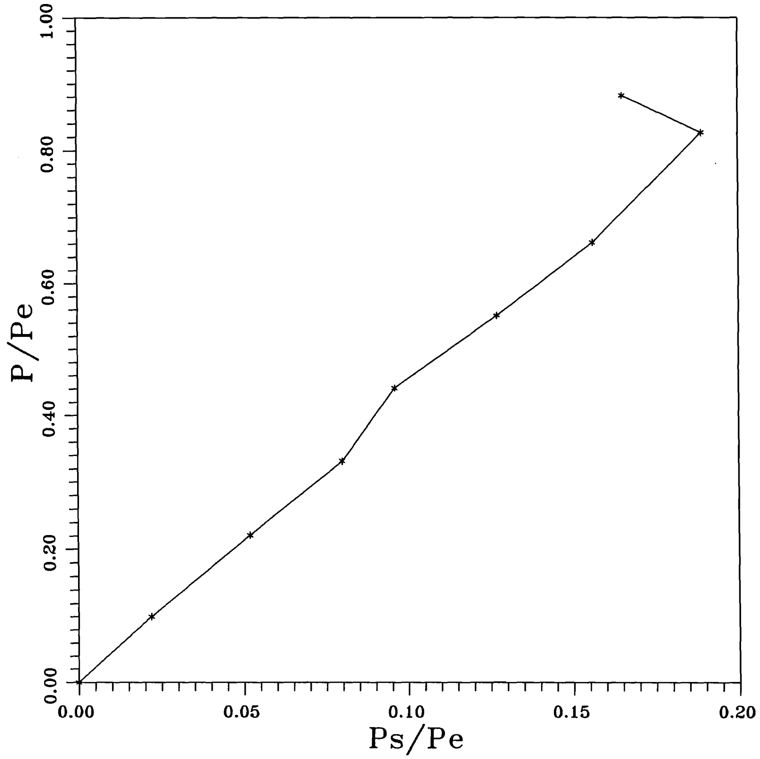

Fig. 3 LOAD Vs SLEEVE FORCE

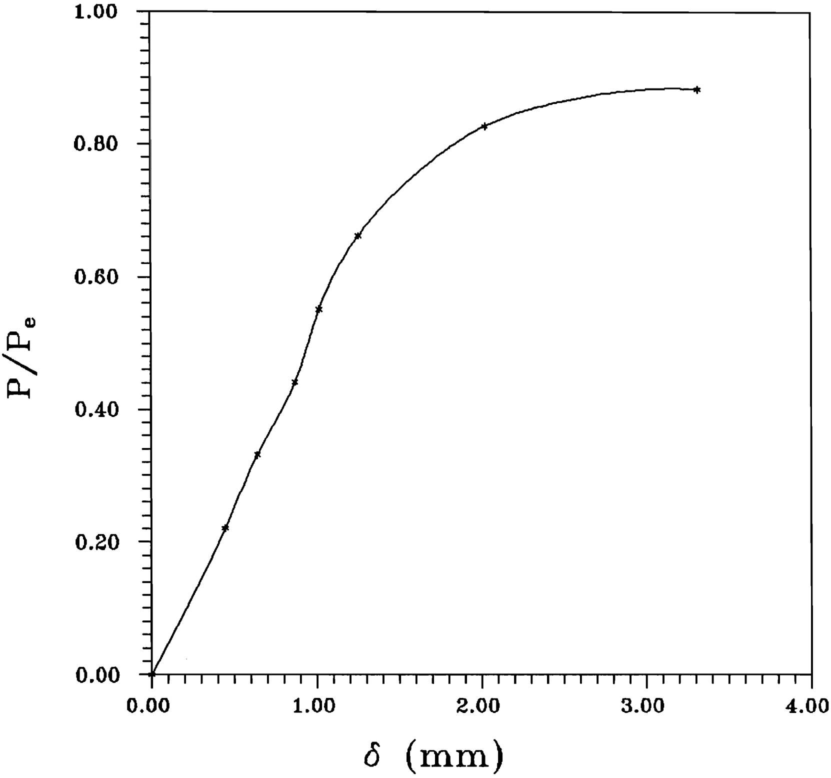

Fig. 4 LOAD Vs DEFLECTION

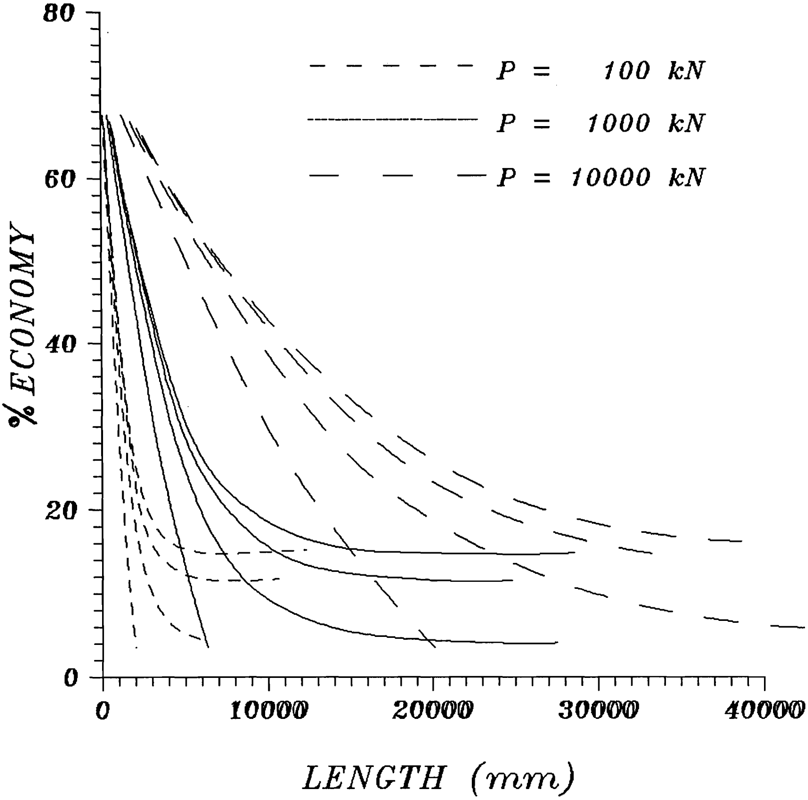

Fig. 5 ECONOMY CHART