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Economic Considerations of Extra Long Flight Conveyors

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BELTCON 5

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1. SUMMARY

In the process of design of an overland conveyor system an attempt was made to compare and analyse the effect of technical parameters on conveying economy. The major technical aspects have been investigated in more detail and changes to design procedure have been suggested.

2. INTRODUCTION

Transportation of bulk solids is of considerable importance to numerous industries. The use of continuous belt conveyors has a proven record in terms of reliability and the ability to handle large volumes of material. Currently 37 500 tons/hour are being comfortably handled at a belt velocity of 7,5 m/s. [1]. Flights of 5 km in length are not an uncommon occurrence. The economic performance of continuous belt conveyors, having recently become a critical factor, has been modelled and studied by various authors [5, 6, 12]. This paper evaluates these factors in the light of specific physical systems.

3. DESCRIPTION

The intended continuous conveyor belt system is 12 900 m long with an overall drop of 39 m.

In terms of the number of conveyor flights, two concepts were considered,

- a single flight of 12 900 m in length, or
- three flights in series over the same distance, with lengths of 5150m, 4300m, and 3450m.

Further, for each of the above, two belt widths were considered, namely:

- 1200 mm wide belt, with a belt velocity of 4,5 m/s
- 1350 mm wide belt, with a belt velocity of 3,66 m/s.

The tonnage used in all calculations is 2200 tons/hour with an average material density of 850 kg/m^3. This constant tonnage assumption puts the single long flight conveyor at an immediate disadvantage. (For example, assuming a conveyor has a availability of 95%, the availability of the three flight conveyor system will effectively be $(0,95)^3$ or 86%. In real terms the long single flight will have a higher availability and thus deliver its quota before that of the three flight system, thus possibly relaxing the single flight design criteria).

It must however be remembered that efficiency of personnel plays an important part in real conveyor performance, but has not been considered at this stage.

A common conveyor friction factor is used for all power and belt tension calculations.

In all cases drives are placed at the head end with a gravity take-up system behind the secondary drive pulley.

The three flight system will have a total of nine drive units (3 per conveyor) while the single flight conveyor, four drive units. Although the 3 drive unit system is known to be the optimum arrangement in terms of power delivery to the belt for a given belt tension, the 4 drive unit system has been specified for the single flight conveyor in an attempt to standardise the required power output of each unit. Here again placing the single flight conveyor at a disadvantage.

Different idler diameters have been specified, depending on belt speed to maintain a constant idler rpm, namely :

- 1350 mm wide belt, idler diameters of 127 mm
- 1200 mm wide belt, idler diameters of 152 mm

The idler spacing is constant along the length of the conveyor. The troughing and return idler spacings are 1,22 m and 3,66 m respectively for all conveyors. The return idler spacing on the long flight conveyor has been reduced from 3,66 m to 2,75 m. (This alleviated the problem of excessive flexing of idler shafts while carrying the higher rated heavier belt).

4. RESULTS

The land profile used for all calculations is shown below (Fig. 1) with the following labeling system :

- Conveyor A, first of three short conveyors with a length of 5150 m
- Conveyor B, the second of the three short conveyors with a length of 4300 m
- Conveyor C, the third and last of the short conveyors, with a length of 3450 m
- Conveyor D, the long single flight conveyor with the total length of 12900 m.

The calculated belt tensions for normal running, start up and braking conditions are shown in figure 2 through figure 13.

The reader's attention is drawn to the characteristic of conveyor D being a sum of the characteristics of conveyors A, B and C. However the magnitudes of belt tensions is far greater for conveyor D.

The belt tensions resulting from the two belt velocities namely 3,66 m/s and 4,5 m/s are also shown.

Figure 1

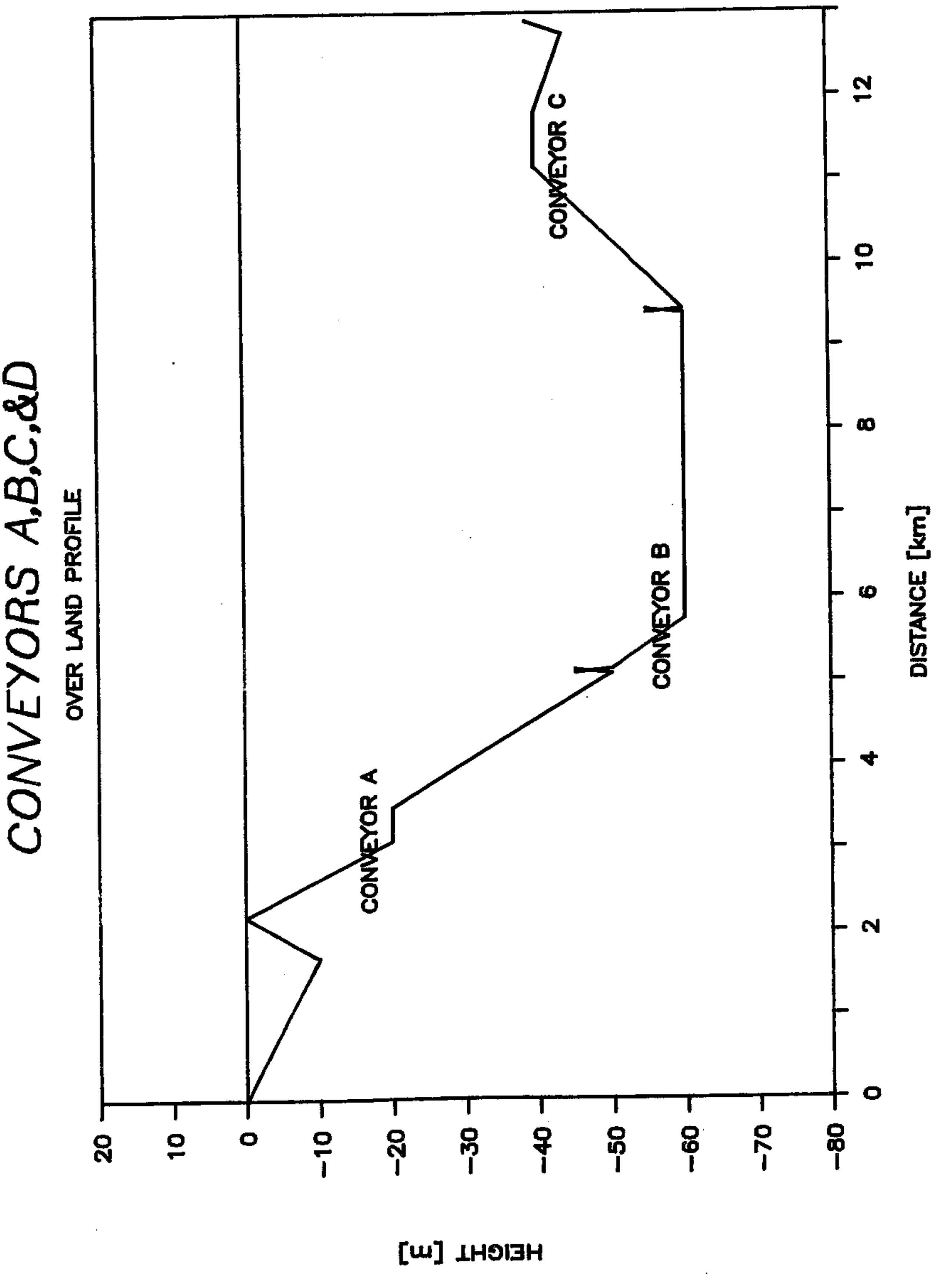
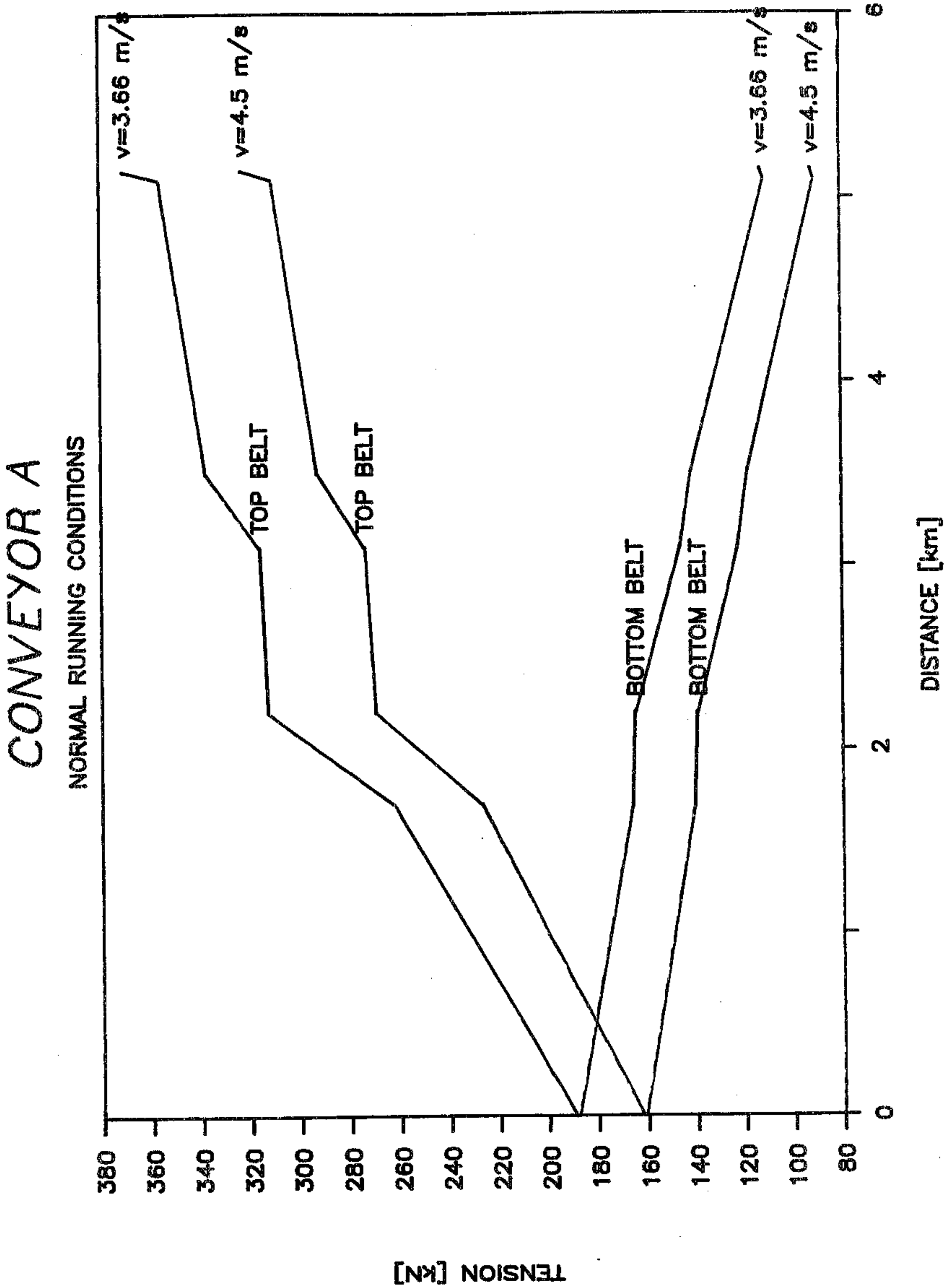
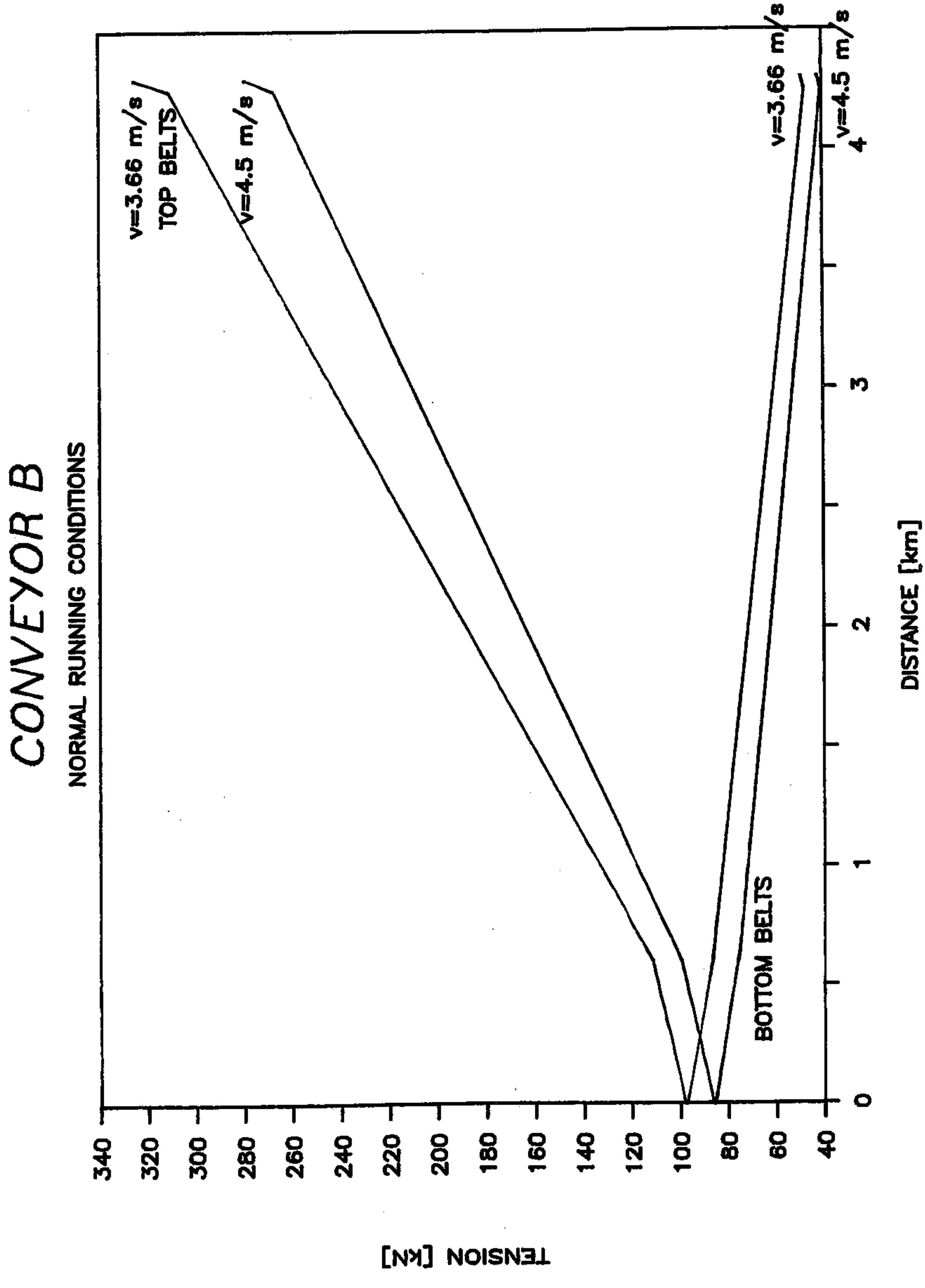
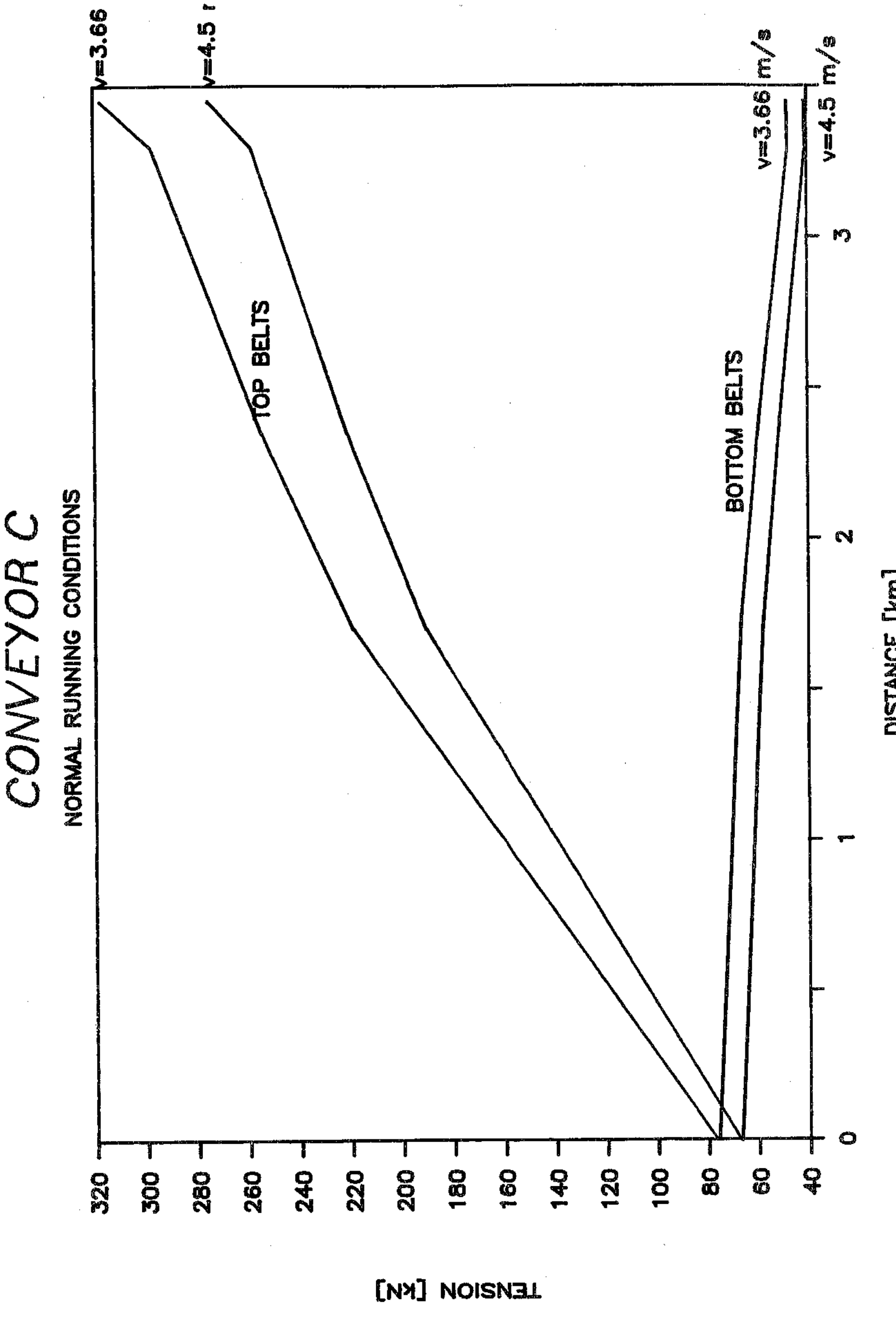
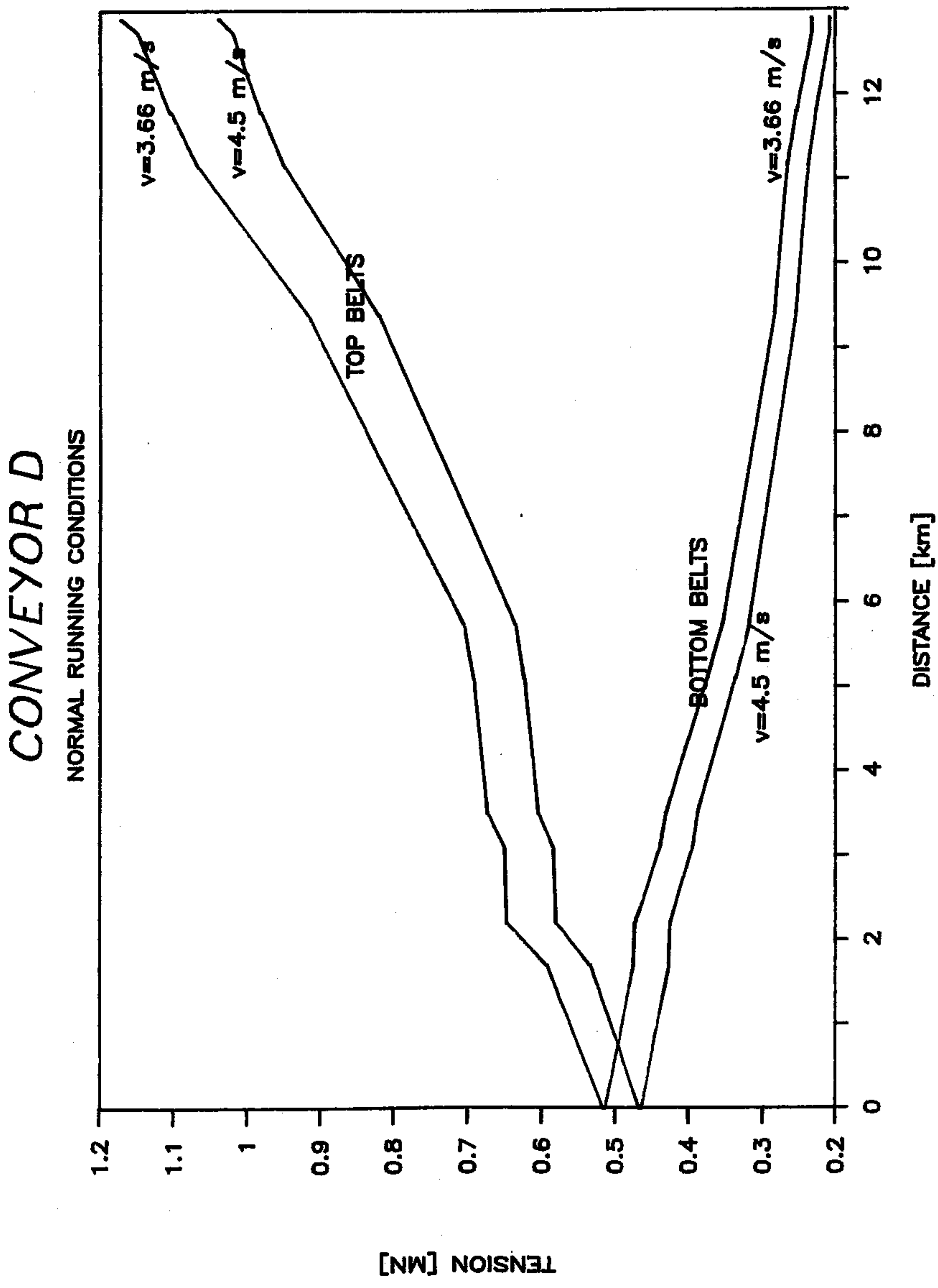

CONVEYORS A,B,C,&D
OVER LAND PROFILE
CONVEYOR A
CONVEYOR B
CONVEYOR C
DISTANCE [km]
HEIGHT [m]
0
2
4
6
8
10
12
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80

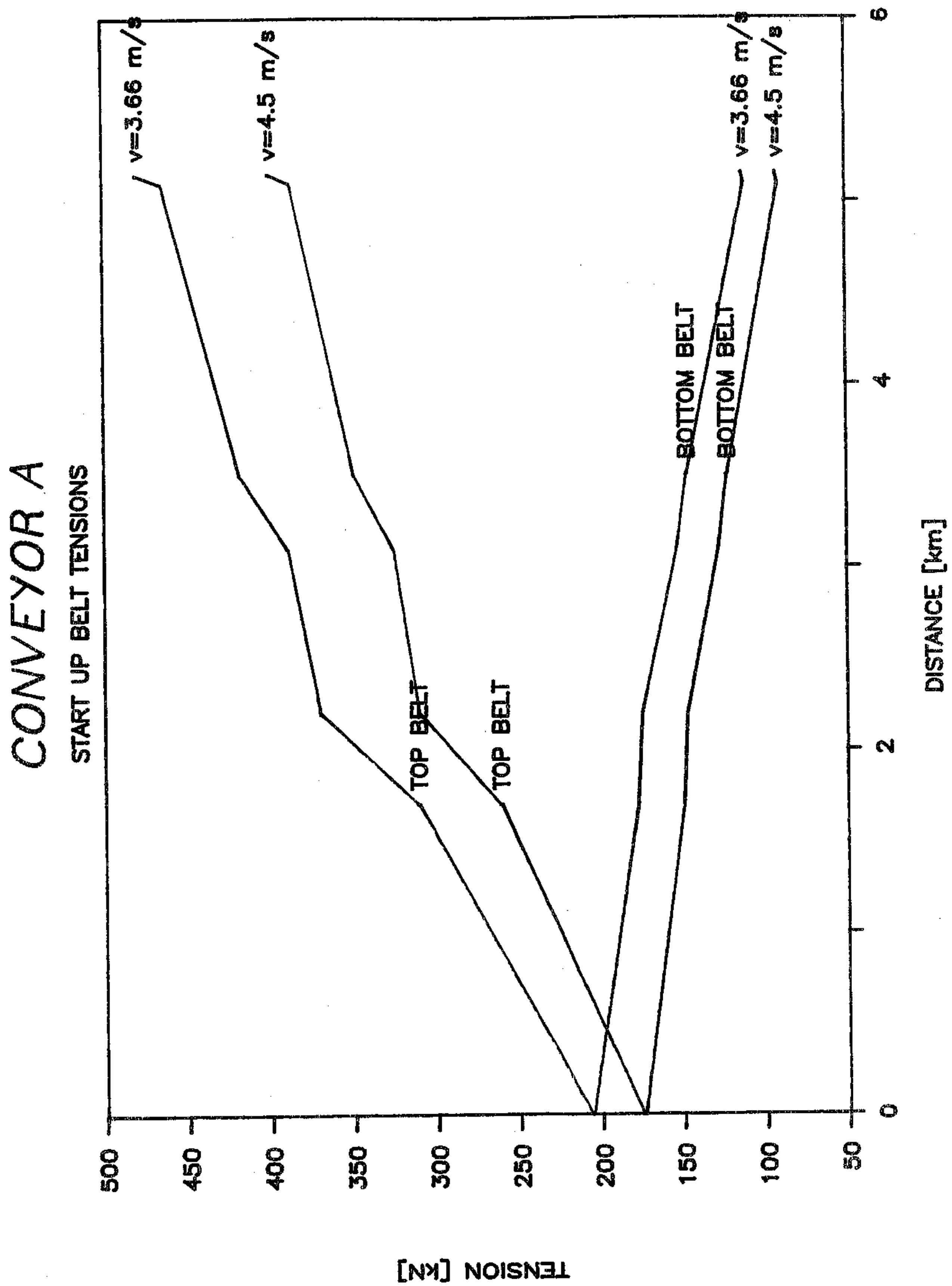
Figure 2

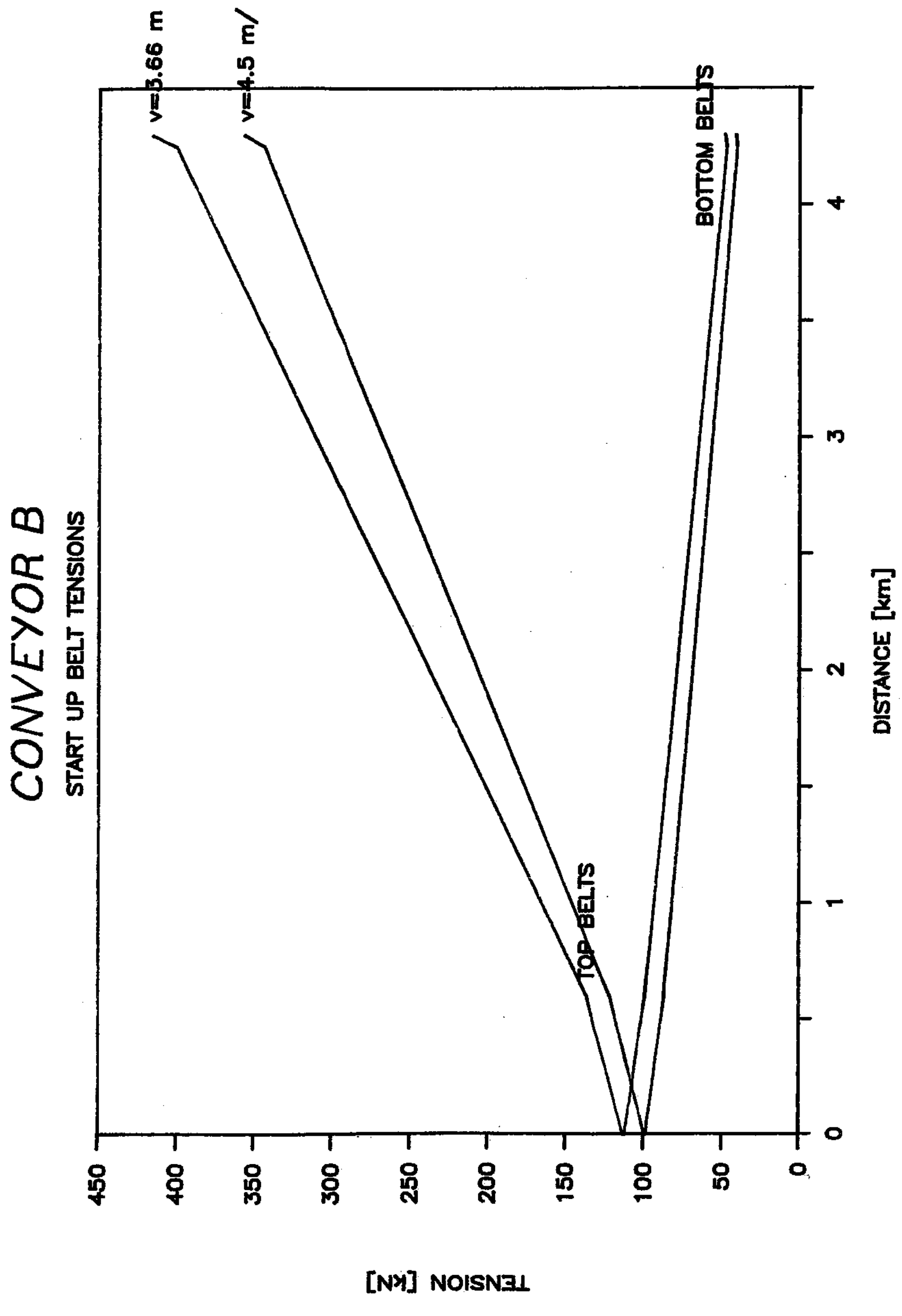

CONVEYOR A
NORMAL RUNNING CONDITIONS
v=3.66 m/s
v=4.5 m/s
TOP BELT
TOP BELT
v=3.66 m/s
v=4.5 m/s
BOTTOM BELT
BOTTOM BELT
TENSION [kN]
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
DISTANCE [km]
0
2
4
6


CONVEYOR B
NORMAL RUNNING CONDITIONS
TOP BELTS
v=3.66 m/s
v=4.5 m/s
BOTTOM BELTS
v=3.66 m/s
v=4.5 m/s
TENSION [kN]
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
DISTANCE [km]
0
1
2
3
4


CONVEYOR C
NORMAL RUNNING CONDITIONS
TOP BELTS
BOTTOM BELTS
v=3.66
v=4.5
v=3.66 m/s
v=4.5 m/s
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
TENSION [kN]
0
1
2
3
DISTANCE [km]


CONVEYOR D
NORMAL RUNNING CONDITIONS
TOP BELTS
v=3.66 m/s
v=4.5 m/s
BOTTOM BELTS
v=3.66 m/s
v=4.5 m/s
TENSION [MN]
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
DISTANCE [km]
0
2
4
6
8
10
12


CONVEYOR A
START UP BELT TENSIONS
TENSION [kN]
DISTANCE [km]
TOP BELT
TOP BELT
BOTTOM BELT
BOTTOM BELT
v=3.66 m/s
v=4.5 m/s
v=3.66 m/s
v=4.5 m/s
500
450
400
350
300
250
200
150
100
50
0
2
4
6


CONVEYOR B
START UP BELT TENSIONS
v=3.66 m
v=4.5 m/
TOP BELTS
BOTTOM BELTS
TENSION [kN]
0
50
100
150
200
250
300
350
400
450
DISTANCE [km]
0
1
2
3
4

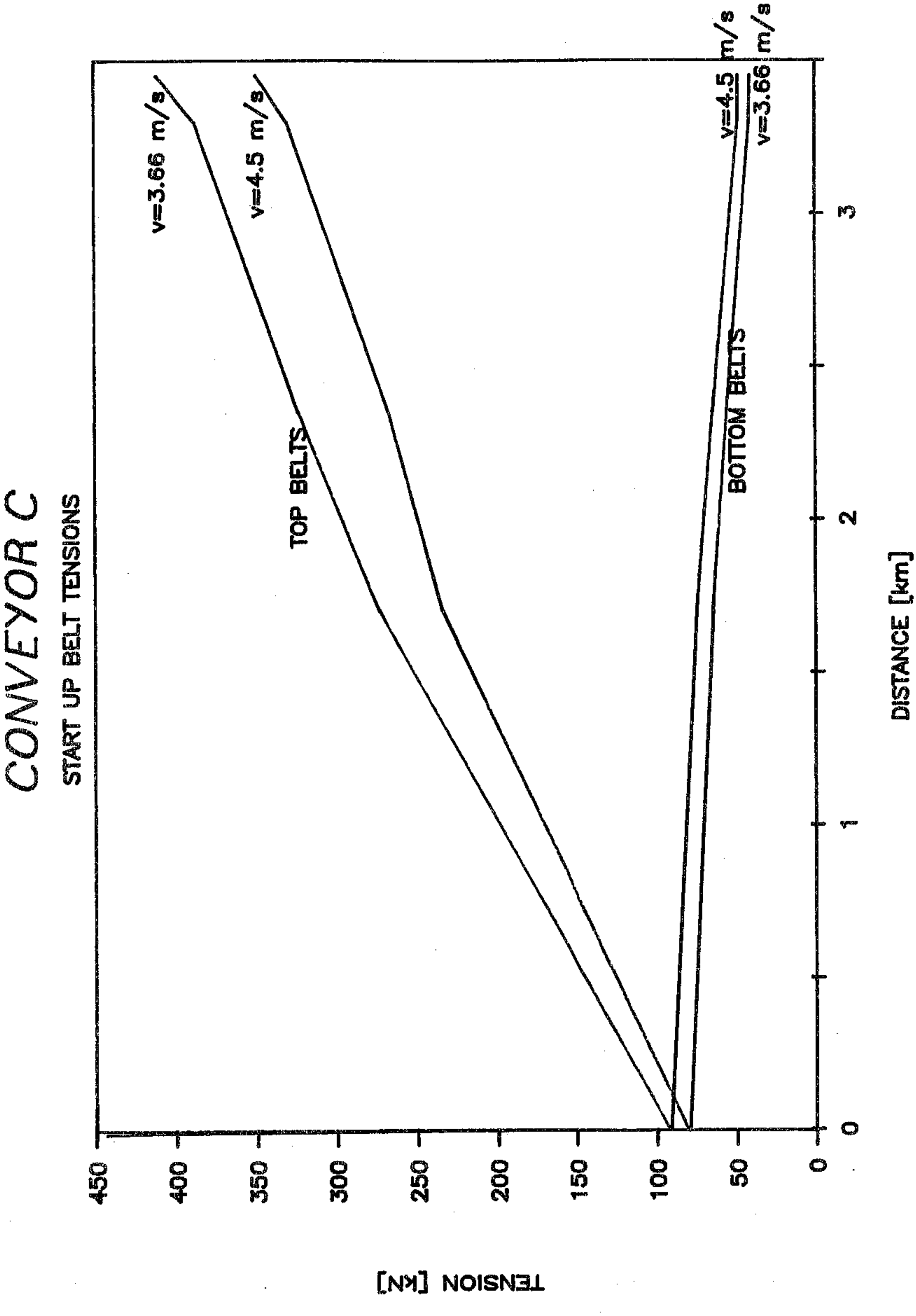
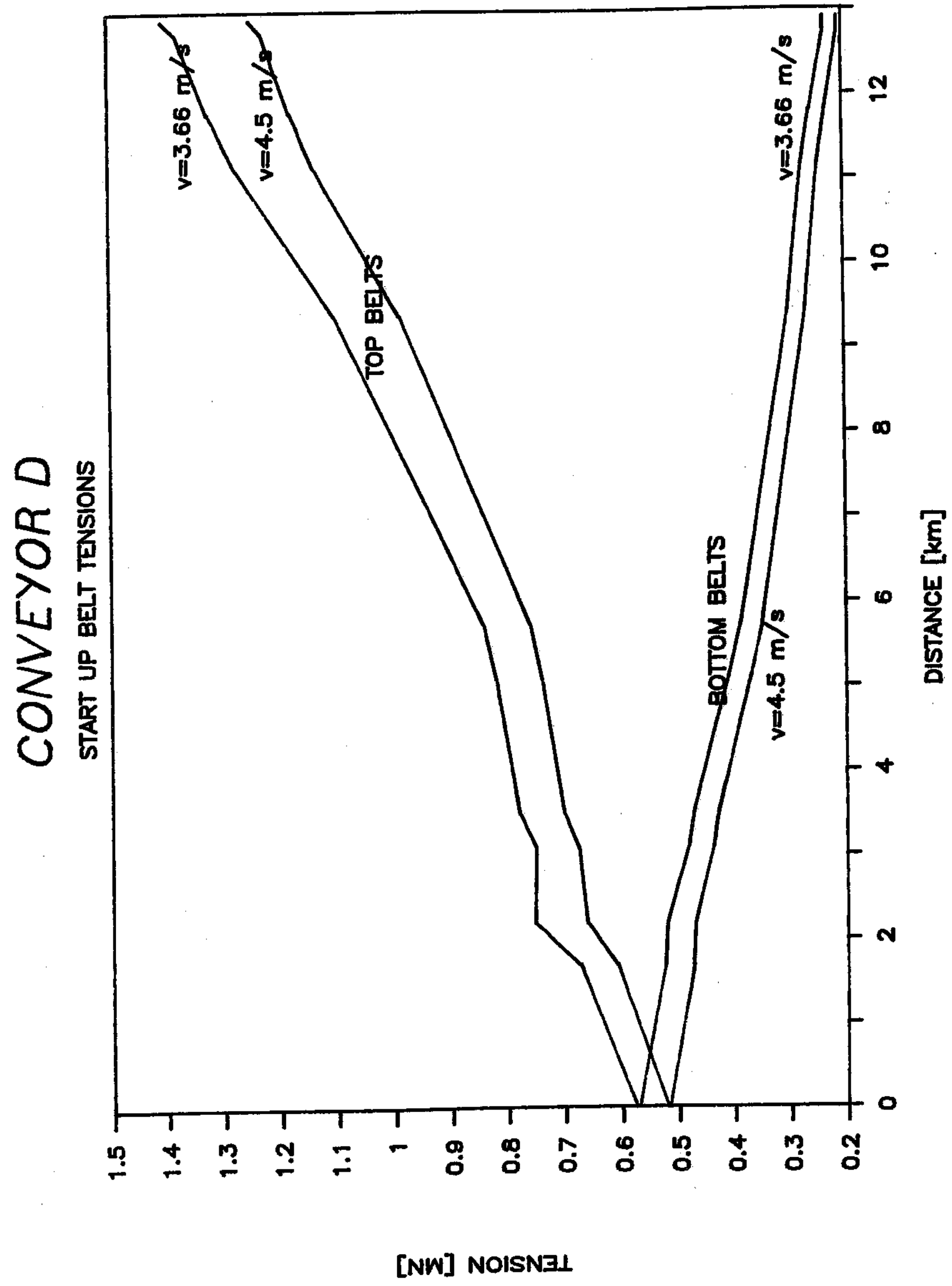

CONVEYOR C
START UP BELT TENSIONS
TOP BELTS
BOTTOM BELTS
v=3.66 m/s
v=4.5 m/s
v=4.5 m/s
v=3.66 m/s
DISTANCE [km]
0
1
2
3
TENSION [kN]
0
50
100
150
200
250
300
350
400
450

Figure 9


CONVEYOR D
START UP BELT TENSIONS
TOP BELTS
BOTTOM BELTS
v=3.66 m/s
v=4.5 m/s
v=3.66 m/s
v=4.5 m/s
TENSION [MN]
DISTANCE [km]
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2
4
6
8
10
12

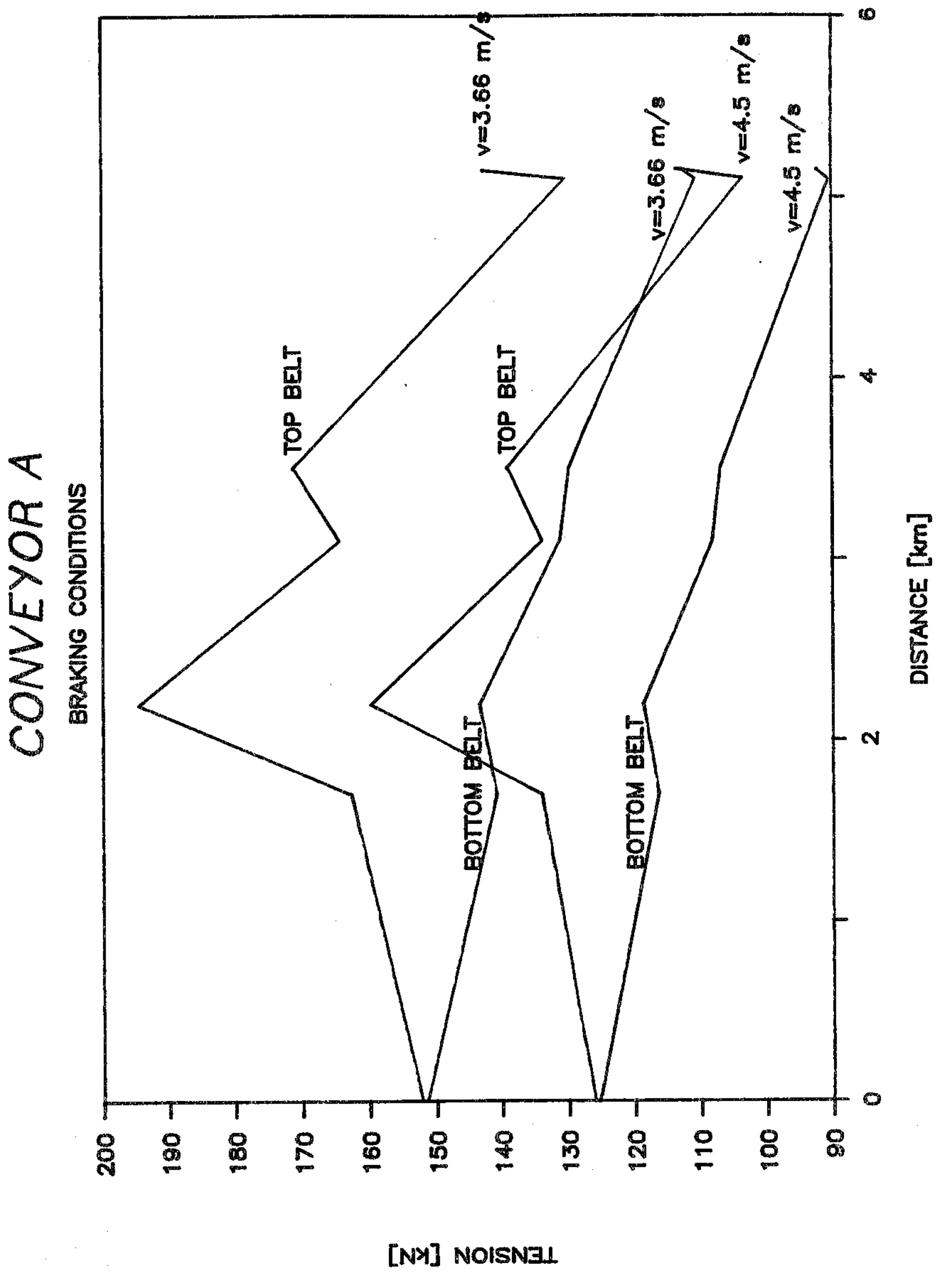
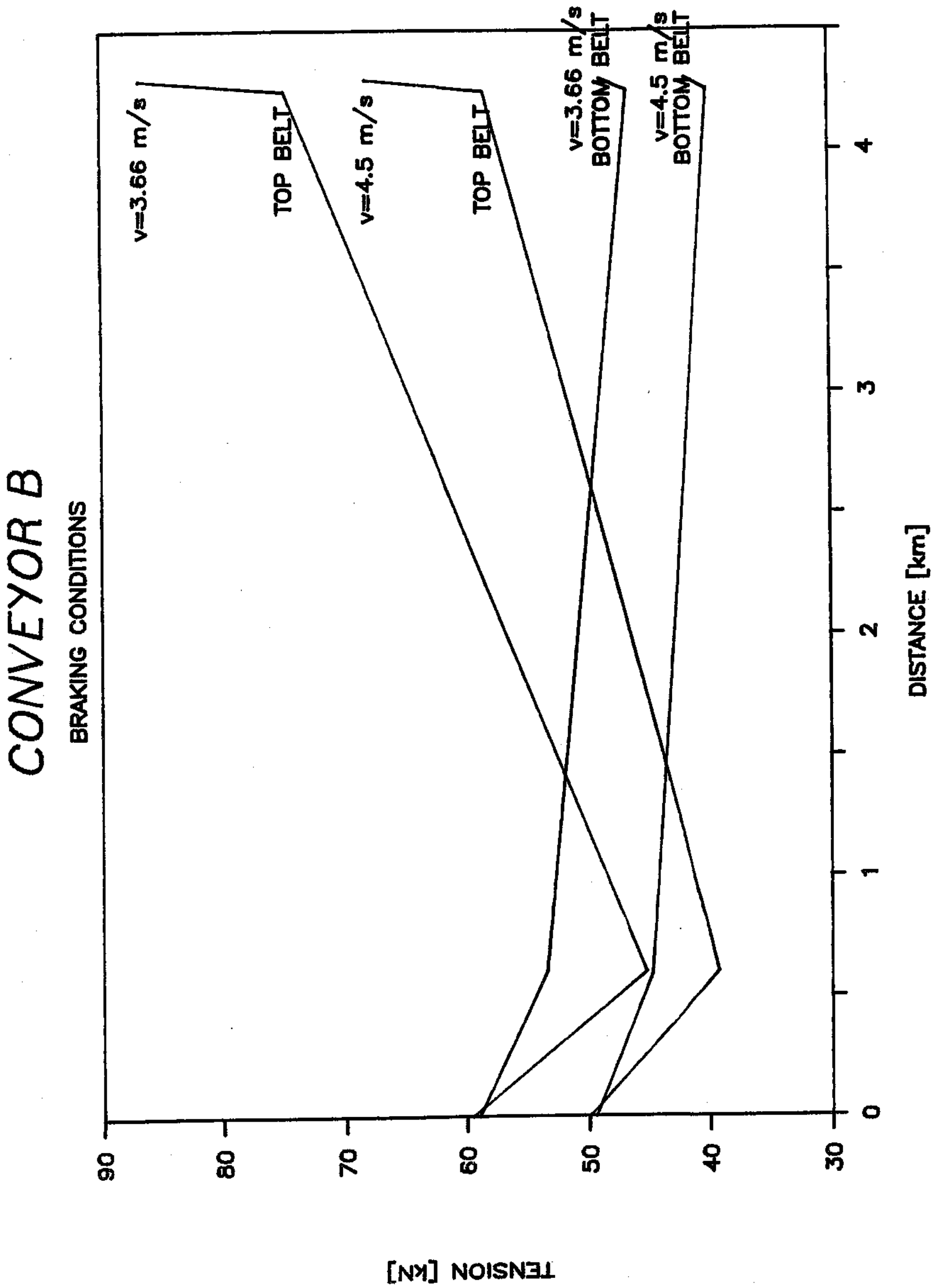
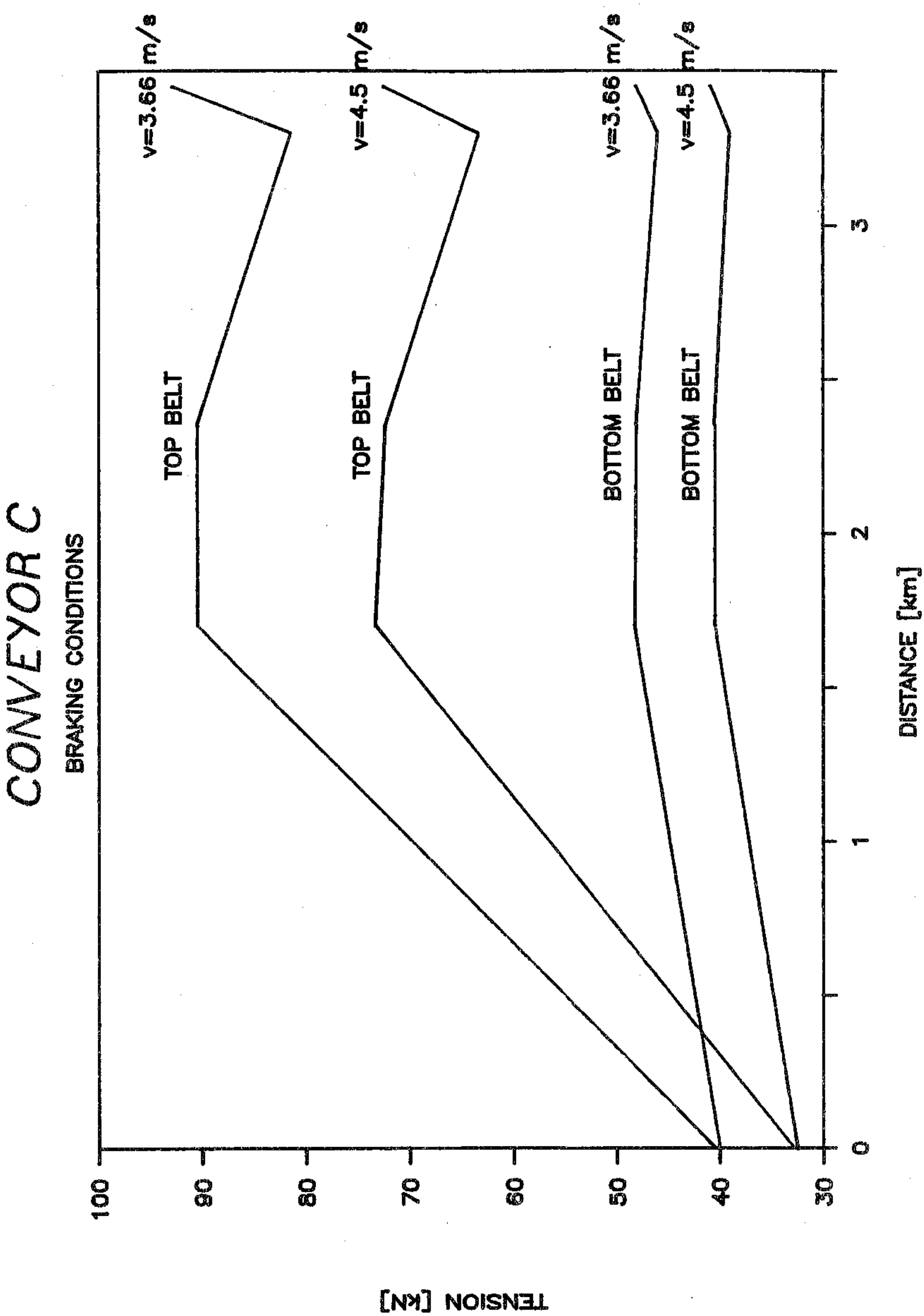
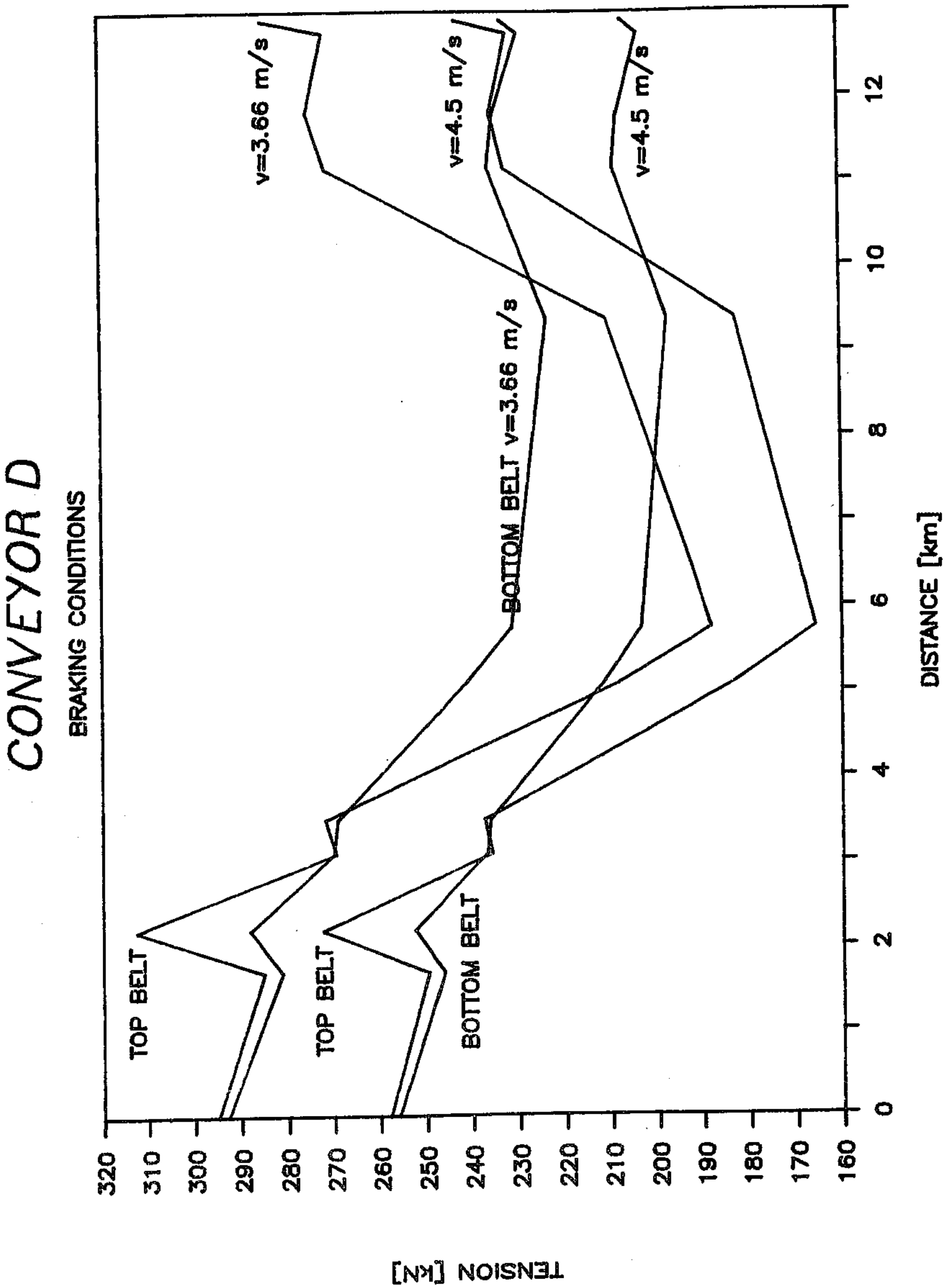

CONVEYOR A
BRAKING CONDITIONS
TOP BELT
TOP BELT
BOTTOM BELT
BOTTOM BELT
v=3.66 m/s
v=3.66 m/s
v=4.5 m/s
v=4.5 m/s
DISTANCE [km]
0
2
4
6
TENSION [kN]
200
190
180
170
160
150
140
130
120
110
100
90

Figure 11


CONVEYOR B
BRAKING CONDITIONS
v=3.66 m/s
TOP BELT
v=4.5 m/s
TOP BELT
v=3.66 m/s
BOTTOM BELT
v=4.5 m/s
BOTTOM BELT
0
1
2
3
4
DISTANCE [km]
90
80
70
60
50
40
30
TENSION [kN]


CONVEYOR C
BRAKING CONDITIONS
v=3.66 m/s
v=4.5 m/s
v=3.66 m/s
v=4.5 m/s
TOP BELT
TOP BELT
BOTTOM BELT
BOTTOM BELT
100
90
80
70
60
50
40
30
TENSION [kN]
0
1
2
3
DISTANCE [km]


CONVEYOR D
BRAKING CONDITIONS
TOP BELT
TOP BELT
BOTTOM BELT
BOTTOM BELT v=3.66 m/s
v=3.66 m/s
v=4.5 m/s
v=4.5 m/s
DISTANCE [km]
TENSION [kN]
0
2
4
6
8
10
12
320
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160

5.1.1 Trends

The relatively large difference between percentage belt and mechanical costs, for long single flight conveyors, suggests an avenue for overall cost reduction. The introduction of methods and/or devices which decrease belt tensions and hence belt class and the cost of the belt, will be accompanied with a small increase in mechanical overheads thus lowering the total cost.

In the case of the three flight arrangement any modification to achieve price gains would require a more sophisticated approach, i.e. the reduction of belt costs with little or no increase in mechanical costs.

The very low percentage of electrical costs to total costs may not be a rule.

Narrower but faster belt configurations generally lead to a decrease of capital costs but will not change the overall ratios between the categories.

It is important to note that within the group of mechanical costs, drive units contribute almost 40%, irrespective of belt width or velocity. However in absolute terms larger drive units are more cost effective. This effectiveness significantly increases with reduced gearbox ratios [10].

5.2 Operational Costs

For the purpose of this evaluation, repair and maintenance of belting was based on the total area of belting [4]. The maintenance of mechanical, structural and electrical equipment has been taken as 5% of respective capital cost.

In many instances a significant percentage of operational costs results from the loss of revenue due to particle size degradation. Regretably no theoretical model could be found relating degradation and various belt conveyor parameters. This omission is possibly to the disadvantage of long single flight, low belt velocity systems.

A comparison of operational costs, shown as a percentage of the maximum operational cost is shown in figure 15.

5.2.1 Trends

Belt maintenance and electrical power are seen to be major contributors to overall operational costs.

The single flight system tends to be more cost effective than the three flight system with a further slight advantage for higher belt velocity.

Figure 16 shows the relationship, again as a percentage of the maximum, between the equivalent annual cost of each system for 30 years of operation.

It is significant that the three flight, high belt velocity system, and the single flight slower belt velocity system achieve very similar results. Again the single flight, high velocity belt system shows the best results.

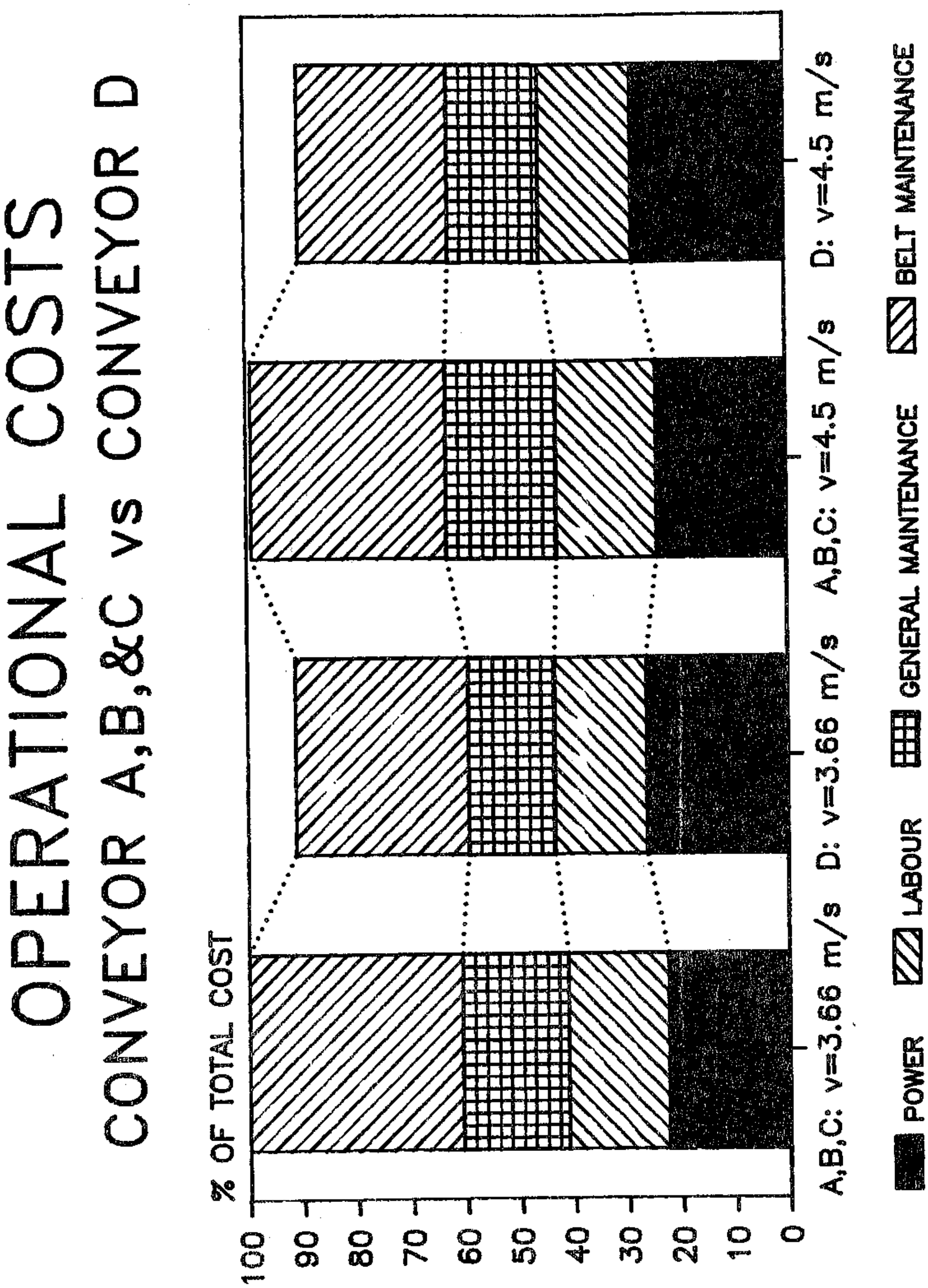
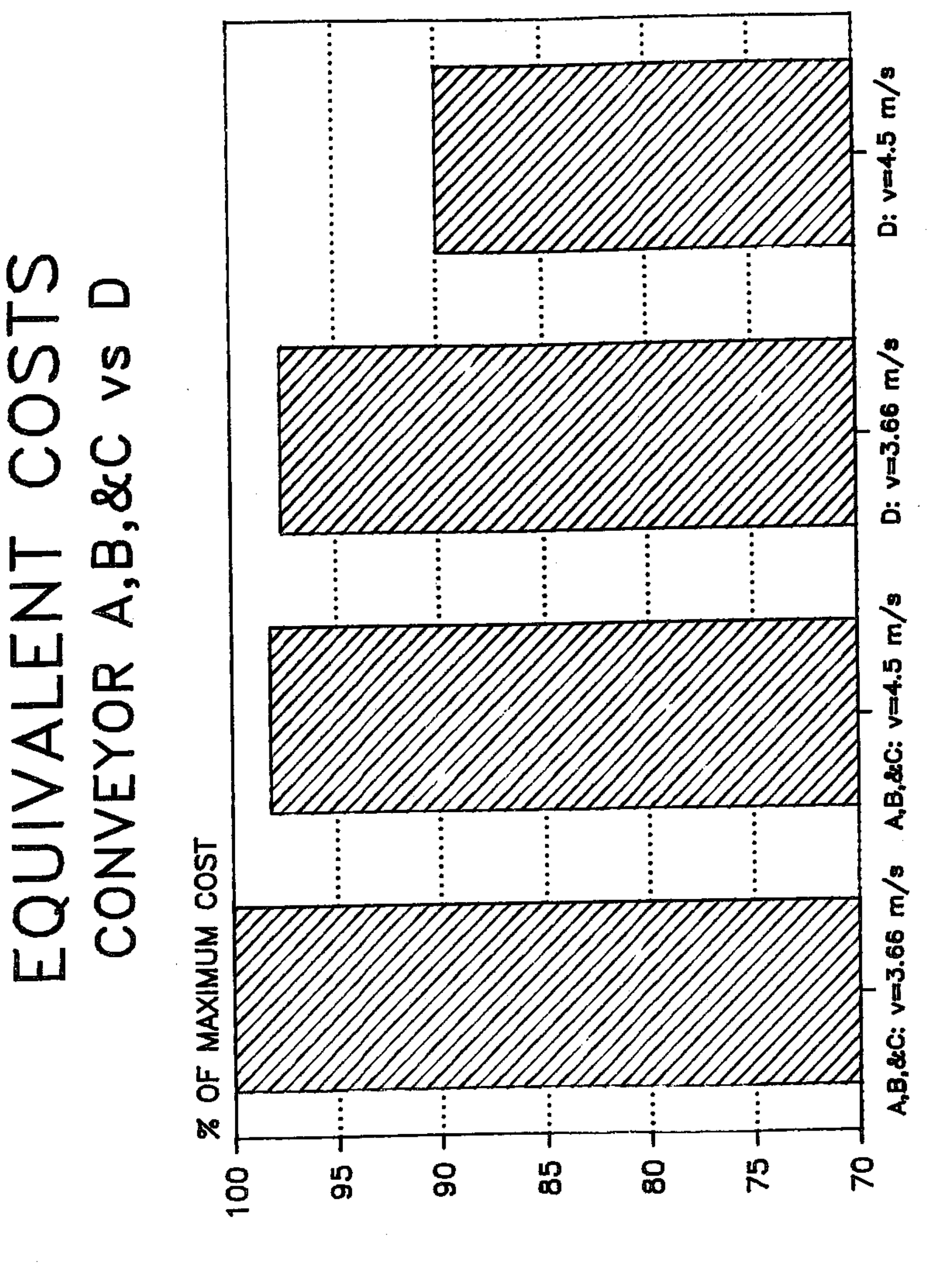

OPERATIONAL COSTS
CONVEYOR A,B,&C vs CONVEYOR D
% OF TOTAL COST
100
90
80
70
60
50
40
30
20
10
0
A,B,C: v=3.66 m/s
D: v=3.66 m/s
A,B,C: v=4.5 m/s
D: v=4.5 m/s
POWER
LABOUR
GENERAL MAINTENANCE
BELT MAINTENANCE

Figure 16



Equivalent annual costs of options.

6. DISCUSSION

EVALUATION OF TECHNICAL PARAMETERS.

6.1 Power Requirements

A constant average friction factor has been assumed for all conveyors. This simplification once again places the long single flight conveyor system at a disadvantage. From field tests it has been established that physical parameters such as; length of conveyor, belt velocity, and idler spacing, do have an influence on the overall conveyor friction factor, as shown in figure 17. [2].

Further, Funke [8] measured systems of significant length working in various harsh climatic conditions, to operate with composite friction factors far below commonly used values.

In commonly used form the total conveyor resistance T_e is described by:

$$T_e = R_h + R_v \quad [N] \qquad (1)$$

where : R_h = resistance to horizontal movement of the belt and material, and rotation of rollers [N]

R_v = resistance to vertical lift of material [N]

and : $$R_h = g \cdot f \cdot l \cdot (M_n + 2 \cdot M_b + M_{rg} + M_{rd}) \qquad (2)$$

$$R_v = M_n \cdot H \cdot g \qquad (3)$$

where : g = 9,81 [m/s²]

M_n = load mass [kg/m]

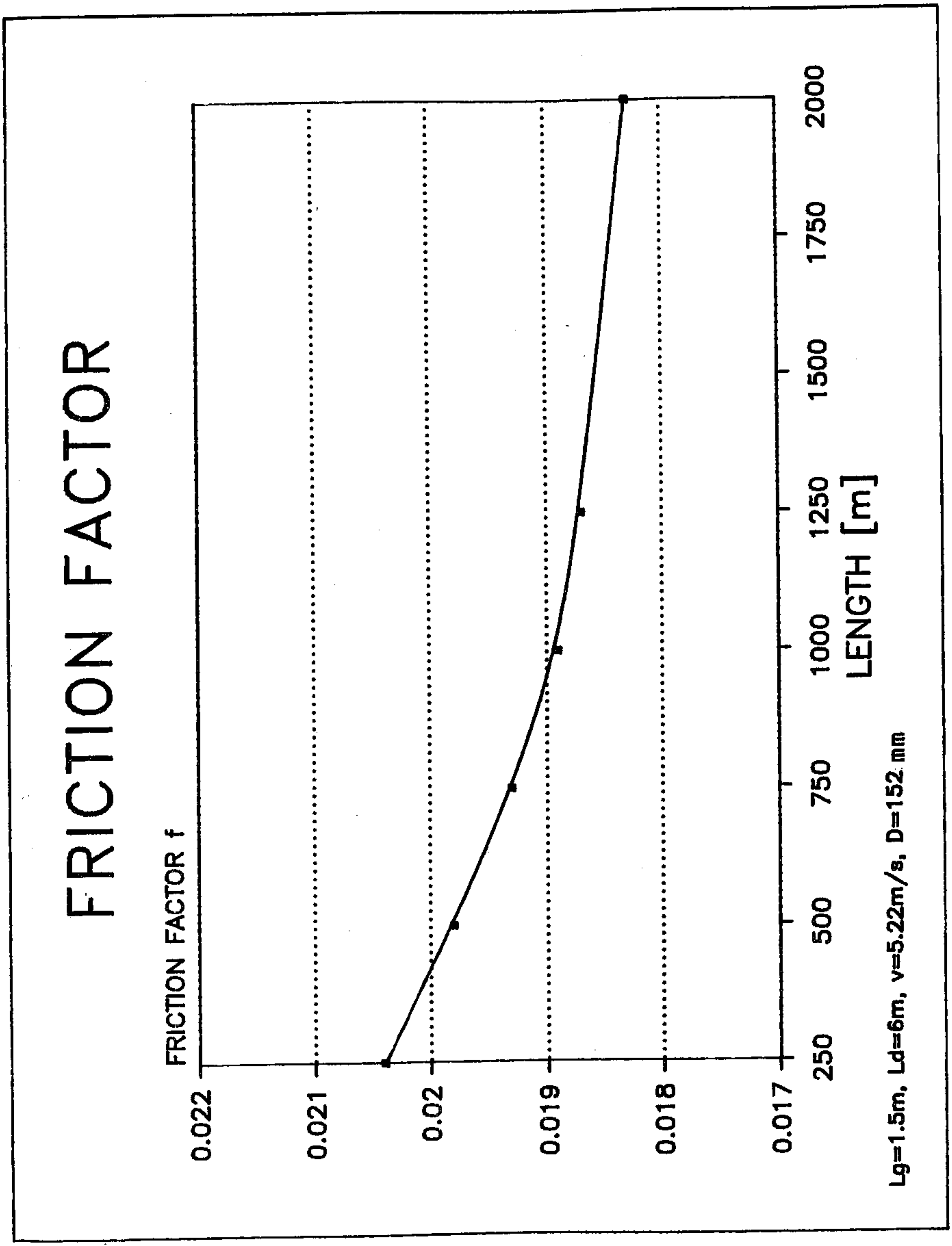
M_b = belt mass [kg/m]

M_{rg} = top idler rotating mass [kg/m]

M_{rd} = bottom idler rotating mass [kg/m]

L = total conveyor length [m]

H = total conveyor lift [m]


FRICTION FACTOR
FRICTION FACTOR f
0.022
0.021
0.02
0.019
0.018
0.017
250
500
750
1000
1250
1500
1750
2000
LENGTH [m]
Lg=1.5m, Ld=6m, v=5.22m/s, D=152 mm

The absorbed power P_A is defined by :

$$P_A = \frac{T_e . v}{1000} \quad [kW] \quad \ldots\ldots (4)$$

where : v = belt velocity [m/s]

By representing the load mass M_n as a function of the required output Q [tons/hr] and substituting equations (1), (2) and (3) into (4) gives :

$$P_A = g \cdot f \cdot L \ (M_{rg} + M_{rd} + 2 \cdot M_b) \frac{v}{1000} + g \cdot f \cdot L \frac{Q}{3600} + g \cdot H \frac{Q}{3600} \ \ldots\ldots (5)$$

The horizontal resistance to movement R_h in equation (3) may also be expressed as follows :

$$R_h = \Sigma R_T + \Sigma R_B \quad \ldots\ldots (6)$$

where : R_T = sum of all top or troughing strand resistances

R_B = sum of all resistances of the bottom return strand

from equation (6)

$$R_h = \Sigma \ (R_1 + R_2 + R_3 + R_4) + \Sigma \ (R^1{}_1 + R^1{}_2 + R^1{}_3) \quad \ldots\ldots (7)$$

where : R_1 = resistance idler to rotate

R_2 = indentation rolling resistance

R_3 = resistance due to belt flexing

R_4 = resistance due to material flexing

Equation (5) can be used to produce the basic requirements for constant power consumption for conveyors of identical lift and length.

$$P_{A1} = P_{A2} \qquad (8)$$

from which results :

$$\frac{f_1}{f_2} = \frac{(M_{rg2} + M_{rd2} + 2 \cdot M_{b2})\ v_2 + Q/3{,}6}{(M_{rg1} + M_{rd1} + 2 \cdot M_{b1})\ v_1 + Q/3{,}6} \qquad (9)$$

The RHS of equation (9) is the required ratio between conveyor friction factors to achieve equal power consumption. From equation (2) and (7) the relationship between friction coefficients can be developed.

$$\frac{f_1}{f_2} = \frac{(M_{n2} + M_{rg2} + M_{rd2} + 2 \cdot M_{b2})}{(M_{n1} + M_{rg1} + M_{rd1} + 2 \cdot M_{b1})} = \frac{(R_{11} + R_{21} + R_{31} + R_{41}) +}{(R_{12} + R_{22} + R_{32} + R_{42}) +}$$

$$\frac{+ (R^1_{11} + R^1_{21} + R^1_{31})}{+ (R^1_{12} + R^1_{22} + R^1_{32})} \qquad (10)$$

Top and bottom strand can be analysed separately and later combined into an average factor f.

$$f = f_{top} \cdot \frac{M_{top}}{\Sigma M} + f_{bot} \cdot \frac{M_{bot}}{\Sigma M} \qquad (11)$$

where : $\Sigma M = M_{top} + M_{bot}$
M_{top} = mass of top strand [kg]
M_{bot} = mass of bottom strand [kg]

If strands are analysed separately it is more convenient to use a simplified eq (10). [11]

$$\frac{f_1}{F_2} = \frac{\Sigma M_2}{\Sigma M_1} \left\{ C_1 \cdot \frac{R_{11}}{R_{12}} + C_2 \cdot \frac{R_{21}}{R_{22}} + C_3 \cdot \left(\frac{R_{31}}{R_{32}} + \frac{R_{41}}{R_{42}}\right) \right\}$$

Evaluation of factors C_1, C_2, C_3 is required for various conditions.

Information regarding each specific resistance must be taken either from direct tests or available literature [2, 3, 8, 11, 13].

For the purpose of this exercise the following additional conditions were imposed:

i. Resistance of idlers to rotate is load independant but influenced by velocity, ambient temperature and roll diameter.

ii. Resistance for material and belt flexing on top strand was calculated for an average tension along conveyor line but was ignored for the return strand.

iii. Only full load conditions were compared.

iv. Idler rollers diameters are :
   - 127 mm for 1350 mm wide belt at 3,66m/s
   - 152 mm for 1200 mm wide belt at 4,5 m/s
   - 180 mm for 1050 mm wide belt at 6,3 m/s (not fully analysed)

From equation (9) the following ratii were required to achieve equal power consumption :

For short conveyors

$$\frac{f_{(3,66)}}{f_{(4,5)}} = 1{,}071$$

$$\frac{f_{(3,66)}}{f_{(6,3)}} = 1{,}228$$

For long conveyors

$$\frac{f_{(3,66)}}{f_{(4,5)}} = 1{,}08$$

$$\frac{f_{(3,66)}}{f_{(6,3)}} = 1{,}258$$

Equations (10) and (11) were used to check relation between friction factors.

For short conveyors ABC the relations are as follows :

$$\frac{f_{(3,66)}}{f_{(4,5)}} = 1,091$$

$$\frac{f_{(3,66)}}{f_{(6,3)}} = 1,02$$

From these comparisons it appears that within existing design parameters, a conveyor with a 1200 mm wide belt running at 4,5 m/s will run with similar power requirement to that of a conveyor with a 1350 mm belt running at 3,66 m/s. The faster belt running at 6,3 m/s does not provide such compensation.
In practice this means power consumption costs may be reduced for faster belts.

Further, the influence of belt length was evaluated for conveyors of similar belt width and velocity.

For 1350 mm wide belt running at 3,66 m/s

$$\frac{f_A}{f_D} = 1,14$$

For 1200 mm wide belt running at 4,5 m/s

$$\frac{f_A}{f_D} = 1,07$$

From this power analysis one may conclude that longer conveyors will require less power per meter of conveyor length and there will be little power cost difference between a belt running at 3,66 m/s and one of 4,5 m/s.

6.2 Belt Life

From the Implimentation Costs Comparison (Fig. 14) it is clear that belting is both technically and economically the major component of the system. This effect further increases with increasing belt lengths.

In the Operational Costing Analysis (Fig. 15) the portion relating to maintenance and repair of belting is related directly to the total area of the belt. The implications of such an approach is that belting is replaced in sections as and when necessary, as compared to a complete replacement at a pre-specified time. This approach is not uncommon.

For example Lachmann [4] recorded, in an open cast mine within the first 8 years of operation 25% of original belting was replaced, while up to 60% in the 11th year.

Thus the influence of various operating conditions cannot be neglected. Records do exist of belt replacement "en masse", but despite intensive research done in this field no theatrical model is currently available predicting belt life.

Let us assume, that contrary to the original assumption of sectional belt replacement, the belt will be replaced "en masse" after a certain period of time. The operational belting costs will now be determined mainly by the expected life of the belt and the frequency of replacement.

Two models may be compared in this regard.

i) Belt wear life is a function of the square root of the length of the belt and the percentage of belt loading [5], namely :

Belt life t (years) is given by :

$$t = 0,102 \cdot (L_e)^{0,5} \cdot \left(2 - \frac{P}{100}\right)^{0,9}$$

where : L_e = total belt length [m]

P = percentage loading of the belt

For two conveyors which differ in length only

$$\frac{L_1}{L_2} = \frac{(L_{e1})^{0,5}}{(L_{e2})^{0,5}}$$

Then in our case for conveyors A and D

$$\frac{L_D}{L_A} = \frac{(12900)^{0,5}}{(5150)^{0,5}} = 1,58$$

Giving an increase in expected life of the longer belt.

ii) The second model [3] suggests the life of the belt t (hours) is represented by

$$t = \frac{A_t \cdot L_e}{v \cdot \Sigma A_p + v \cdot L_e \cdot A_j} \quad [hr]$$

where : A_t = work required for complete wear of belt covers [J]

A_p = work required to perform point damage to the belt [J]

A_j = work required to perform continuous damage to the belt, e.g. a longitudinal cut [J]

This formula can be simplified to the following :

$$t = \frac{X \cdot L_e \cdot B}{Y \cdot h_p + Z \cdot L_e} \quad [hr]$$

where : X, Y, Z = factors combining such parameters as : type of belting, conveyed tonnage and conditions of operation and maintenance.

L_e = total belt length [m]

B = belt width [m]

h_p = drop at transfer point [m]

One can notice that product $L_e \cdot B$ is total area of belting.

Once again if two conveyors of identical parameters, but different lengths, are compared the following applies :

$$\frac{t_1}{t_2} = \frac{L_{e1}\ (Y \cdot h_{p2} + Z \cdot L_{e2})}{L_{e2}\ (Y \cdot h_{p1} + Z \cdot L_{e1})} = \frac{L_{e1}}{L_{e2}} \cdot \frac{(h_{p2} + Z/Y \cdot L_{e2})}{(h_{p1} + Z/Y \cdot L_{e1})}$$

where $0{,}003 \leq Z/Y \leq 0{,}1$

Substituting values from conveyors A and D :

where : L_{eD} = 2 x 12 900 = 25 800 m

L_{eA} = 2 x 5 150 = 10 300 m

h_p = 5 m

$$\frac{t_1}{t_2} = 1{,}03 \quad \text{or} \quad L_1 \approx L_2$$

Showing that in this case only the belt width will have significant influence on expected belt life.

For a fixed tonnage the wider belt may run slower than the narrower belt. For conveyor D

$B_1 = 1{,}350$ m

$B_2 = 1{,}200$ m

$$\frac{t_1}{t_2} = 1{,}13$$

It is important to mention that a new aspect in belt calculation and sizing is relevant here, namely dynamic splice strength. If, as suggested by Flebbe [9] dynamic splice strength becomes the major criterion for belt sizing, the maximum number of belt cycles may influence belt life considerations.

One may conclude that the two presented models of belt life expectancy show longer and/or wider belts improve performance.

7. CONCLUSIONS

For the analysed systems the following trends were observed :

i) Increased conveyor length has a marked effect on the capital cost of a system. The critical factor is the length of belting installed.

ii) For long conveyors methods or devices which decrease belting costs are financially beneficial. The decrease of belting costs may be achieved by the reduction of either the belt width or the belt rating.

iii) Electrical power and belt maintenance form the major part of operational costs.

Initial indications are that electrical power costs per unit length of belt may be maintained fairly constant, independent of increased conveyor length, velocity, or number of flights.

Belt maintenance costs need further evaluation.

The present link between costs and belting area favour narrow belts, while ignoring the influence of belt velocity and conveyor length.

iv) Long term comparisons favour long flight conveyor belt systems running at higher velocities, while the expected working life of the design has an influence on equivalent costs of operation.

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