STRENGTH ANALYSIS OF STEEL ROPE ON FREIGHT ELEVATOR WITH A HOIST LIFTING CAPACITY OF 3 TONS

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ABSTRACT—*Analysis of the selection and knowing the strength of the steel rope on the goods elevator is quite important. In the construction of this freight elevator with a lifting capacity of 3 tons, the Mitsubishi Electric Hoist brand at PT. X uses steel rope type 6 x 29 or 6 x 14/7+7/4.1 Filler FC (fiber core) with 6 strands each consisting of 29 wires of different diameters. Steel ropes equipped with a fiber core are coded FC (fibre core), to distinguish them from ropes equipped with a steel wire core or iron wire coded IWC (independent wire core). The latter does not provide lubrication and is not used for elevators because it is not flexible. For the results of the analysis of the strength of the steel ropes produced, the total load on the elevator is 2662,5 kg, the Hoist used with a capacity of 3 Tons in the safety point Q a total of 2662, 5 kg (2, 6 Tons) < 3000 kg (3 Tons), safety tolerance 11,25%. At the maximum stress S = 1429,91 kg, less than the allowable stress S = 1965,270 kg, the safety tolerance is 27,24 %. The maximum fracture load is P = 7864,52 kg, smaller than the fracture stress allowed by the SNI standard (Pb) = 10808.99 kg, safety tolerance is 27,24%. At the maximum tensile stress on steel rope tension t = 9,09 kg/mm2, smaller than the allowable tensile stress = 29,09 kg/mm2, the tensile stress safety tolerance is 68,75 %. To analyze the conclusion that the elevator hoist and the wire rope are safe to use, and have a longer lifetime.*

Keywords: *Wire Rope (steel rope), FC (Fibre Core), IWC (independent Wire Core), Safety, Life Time*

1. INTRODUCTION

The Goods Elevator lifting system is very necessary in the industrial high-rise building, which will be more effective and efficient, than moving goods using human labor [1]. The development of layouts in companies in big cities will have difficulty in procuring land, due to the high cost of land areas in big cities, so that the expansion of the industrial area will be carried out in the process of increasing buildings upwards by increasing floors. Therefore, lifting equipment will be needed to move goods.

Based on Buckman Charles, 1994 data on elevator accidents in the United States amounted to 2000 elevators per year. For Indonesia, elevator accidents have also occurred frequently. One of the factors is not paying attention to the standard selection of components that are quite important, one of which is wire rope steel [3]. Periodic inspection and maintenance on the elevator aircraft is very important, especially on the steel rope (wire rope) [9].

1.1 Research Objectives

1. Identify the safe point of maximum total load on the elevator.
2. Identify the maximum stress and allowable stress.
3. To identify the maximum permissible fracture load according to SNI standards.
4. Identifying the maximum tensile stress on steel rope against the permissible tensile stress of steel rope.

1. Definition and Type of Steel Rope

Special tensile steel ropes for elevators must be made of steel wire that is strong enough, but limp enough to withstand bending, where the rope moves back and forth through the wheels [5]. Steel ropes have chains, but also have disadvantages. The advantages are, resistant to shock loads, when it will break showing a brittle sign on one of the wires. Has good elasticity, and is not noisy when used [10]. The fracture limit of steel wire elements is approximately 130 kgf/mm2 to 200 kgf/mm2 (high content carbon steel).

A typical rope construction for an elevator consists of 6 spindles wound together, left or right with a center core of sisal manila henep fibers, which are saturated with lubricating oil [2]. Each spindle consists of 19 wires, such as 9.9.1, meaning 9 outside wires, 1 in the center and 9 between them. Usually the 9 outer steel wire elements are made of "soft" steel (130 kgf/mm2) to match the friction with the cast iron pulley wheel, without causing excessive wear. Rope construction is often called or written 6 x 19 or 6 x 9.9.1. FC (fiber core). If in use there is a 6 x 29 steel rope or 6 x 14/7+7/4.1 FC (fibre core) [4]. In Figures 1 and 2 there are several examples of rope construction forms and winding directions.

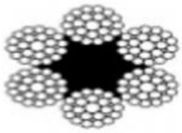
Design/Construction	6 x Fi(29) FC 6 x 29(14/7+7/1) Filler FC
Cross section	
Wire arrangement	6 strands each consisting of 29 different diameter wires, cores of fiber

Figure 1. Construction of Steel Ropes

In terms of the direction of the twist, the rope is categorized into 2 types, which are:

1. *Regular lay*, if the direction of the wire twist is opposite to the direction of the twist and strand.
2. *Lang lay*, if the direction of wire twist is the same direction as the twist and strand.

The advantage of lang lay is that the rope extensibility is smaller which is 0.1% only compared to regular lay 0.5%. The pressure on the pulley groove is smaller so that it is more durable and more flexible, does not have a rigid nature (kicking) when it wants to be installed. Lang lay is used for high-speed elevator installations above 300 m/min, and cross distances above 200 m [6].

Lang lay is also more resistant to fatigue, but the fracture limit is approximately 10% smaller than regular lay. For example, on a 13 mm diameter rope, for regular lay the fracture limit is 6500 kgf, while in lang lay it is approximately 5800 kgf [6].

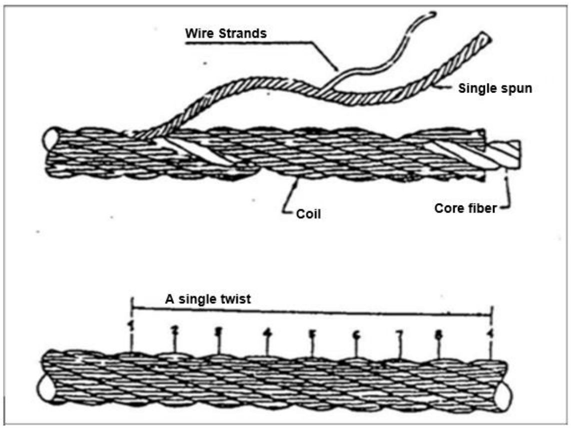


Figure 2. Direction of Steel Rope Twists

3. METHODOLOGY

Based on the data that will be analyzed based on the hoist used, the specifications are as follows:

1. Steel rope type 6 x Fi (29), diameter 13 mm
2. Hoist capacity : 3 Tons
3. Cage length : 1,5 m
4. Cage width : 1,5 m
5. Load : 1 Ton / 1000 kg

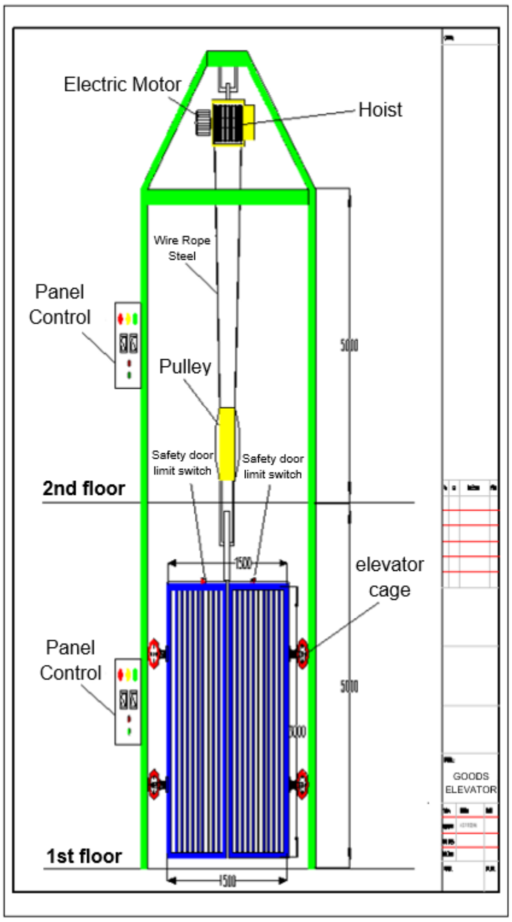


Figure 3. Goods Elevator Construction

Figure 4. Goods Elevator Hoist

Figure 5. Goods Elevator Pully

Table 1. Goods Elevator Components

No.	Components	Materials	Quantity	Size Model
1	Goods Elevator Frame	H beam iron	10 bars	UK 200 x 150 mm
2	Train cage	Holo steel	6 bars	UK 60 x 60 mm
3	Carriage cage door	Angle iron	4 bars	UK 50 x 50 mm
4	Roller	nylon material	4 pcs	UK 4 inch
5	Limits switch roller	Autonic	4 pcs	1 no + nc
6	Control panel	Custom	2 unit	Electrical contractor
7	Hoist motor	Mitsubishi brand	1 unit	3 tons capacity
8	Wire rope steel	Warington seal	15 m	6 x Fi(29), diameter 13 mm

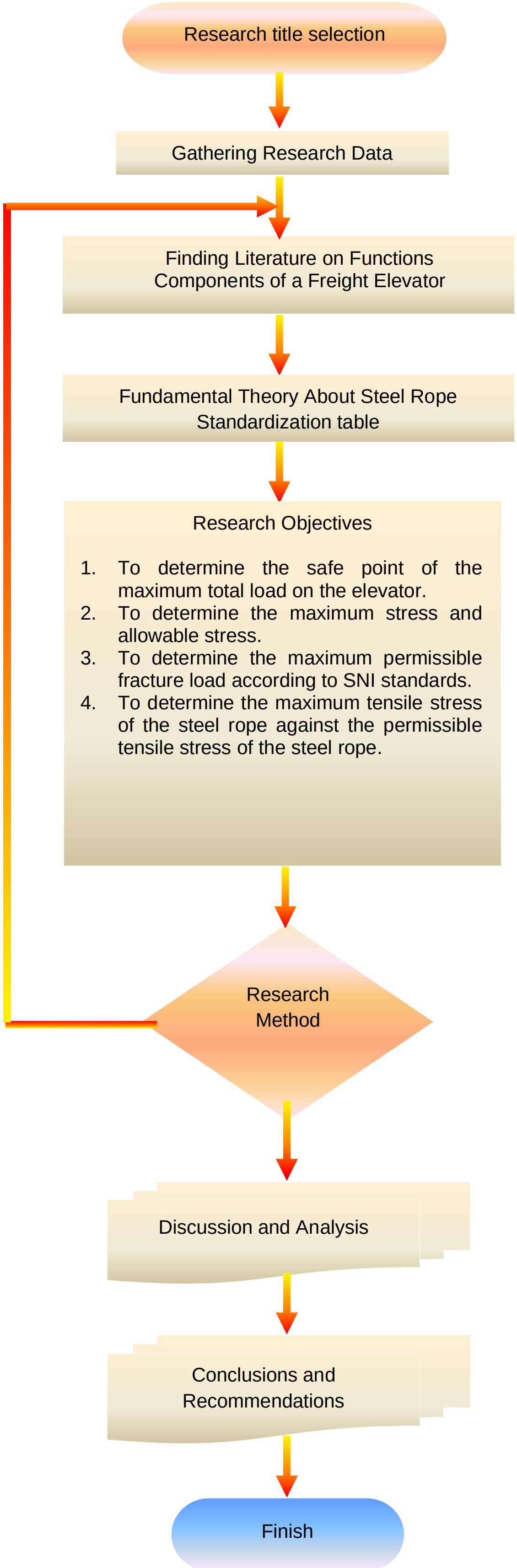


Figure 6. Flow Chart of Research Method

3.1 Weight Analysis of Train Cage

The freight elevator cage can be determined by the following equation:

"Equation (1)"

$$G\ cage = 300 + 125\ F \tag{1}$$

Q = 1000 kg

Where:
F = floor area in m
Q = capacity, in kg

"Equation (2)"

$$F\ (Cage\ Area) = length\ \times width \tag{2}$$

G cage (WO) = G cage + 0.5 Q
G cage (WO) = 300 + 125F

F (Cage Area) = 1.5 m × 1.5 m
F (Cage Area) = 2.25 m^2

G cage = 300 + 125F
G cage = 300 + 125(2.25 m^2)
G cage = 300 + 281.25
G cage = 581.25 kg

Weight of Carriage Cage

G cage = 581.25 kg

G cage (WO) = G cage + 0.5 Q
WO = 581.25 kg + 0.5 x 1000 kg
WO = 581.25 kg + 500 kg
WO = 1081.25 kg

3.2 Total Load Analysis of the Goods Elevator

"Equation (3)"

$$Q_{total} = Q + WM + WO \tag{3}$$

Where:
Q = Load capacity of goods in planning (1 Ton)
WM = Weight of the train cage
WO = Weight of cage weight

Q total = Q + WM + WO
Q total = 1000 + 581.25 + 1081.25
Q total = 2662.5 kg

Table 2. Load Analysis of 3 Ton Hoist Capacity

No.	Cage Area	F	Q	G cage (WO) = G cage + 0.5 Q	Q total = Q + WM + WO	total weight limit
	m	m	kg	If there is a change in the load Q	kg	kg
1	1.5 × 1.5	2.25	1000	1081.25	2662.5	3000
2	1.5 × 1.5	2.25	1100	1131.25	2812.5	3000
3	1.5 × 1.5	2.25	1200	1181.25	2962.5	3000
4	1.5 × 1.5	2.25	1300	1231.25	3112.5	3000
5	1.5 × 1.5	2.25	1400	1281.25	3262.5	3000
6	1.5 × 1.5	2.25	1500	1331.25	3412.5	3000
7	1.5 × 1.5	2.25	1600	1381.25	3562.5	3000
8	1.5 × 1.5	2.25	1700	1431.25	3712.5	3000
9	1.5 × 1.5	2.25	1800	1481.25	3862.5	3000
10	1.5 × 1.5	2.25	1900	1531.25	4012.5	3000

From the results of 10 trials with different loads, the load weight is 1 ton or 1000 kg, the total load on the elevator is 2662.5 kg, so the hoist used is 3 tons in a safe point Q total 2662, 5 kg (2.6 tons) < 3000 kg (3 tons), safety tolerance 11.25%. And from the analysis for the maximum load weight limit is 1200 kg with a total load of 2965 kg or still below the hoist capacity of 3 tons (3000 kg).

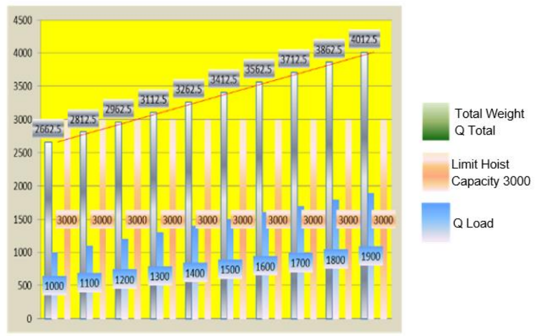


Figure 7. Load Analysis of Hoist Capacity 3

From Figure 6, it can be observed that the heavier the load, the greater the hoist capacity required.

3.3 Analysis of Maximum Rope Stress

"Equation (4)"

$$S = \frac{Q_{Total}}{n\ \times\ \eta\ \times\ \eta 1} \tag{4}$$

Where:
Q = Total elevator capacity
n = Number of buffer pulleys (suspense) = 2
η = Pulley efficiency = 0.95
η1= Efficiency due to rope losses due to stiffness when rolling on the drum = 0.98

Thus:
S = 2662.5 / 2 x 0.95 x 0.98
S = 1429.91 kg

Therefore:

The maximum stress is
S = 1429.91 kg

Rope strength under maximum load

"Equation (5)"

$$S = \frac{P}{K} \quad (5)$$

P = Inner rope breaking strength
K = Safety factor (5.5)
P = S x K
P = 1429.91 kg x 5.5
P = 7864.52 kg

Thus the maximum breaking load is
P = 7864.52 kg

Table 3. Analysis of Maximum Stress against Allowable Stress

Q total = Q + WM + WO	n	η	η1	$S = \frac{Q_{Total}}{n \times \eta \times \eta 1}$	S = Allowable stress
	Number of buffer pulleys	Pulley efficiency	efficiency of rope loss		
kg				kg	kg
2662.5	2	0.95	0.98	1429.91	1965.27
2812.5	2	0.95	0.98	1510.47	1965.27
2962.5	2	0.95	0.98	1591.03	1965.27
3112.5	2	0.95	0.98	1671.59	1965.27
3262.5	2	0.95	0.98	1752.15	1965.27
3412.5	2	0.95	0.98	1832.71	1965.27
3562.5	2	0.95	0.98	1913.27	1965.27
3712.5	2	0.95	0.98	1993.82	1965.27
3862.5	2	0.95	0.98	2074.38	1965.27
4012.5	2	0.95	0.98	2154.94	1965.27

From the results of 10 experiments with different load loads can be viewed in table 3 then with a total weight of 2665kg produces a maximum stress of 1429.91 kg smaller than the allowable stress of 1965.27 kg, a safety tolerance of 27.24%. From the results of table 3 with 10 times test analysis, the maximum allowable load is 3562.5 kg with a maximum stress of 1913.27 or smaller than the maximum allowable stress of 1965.27 kg.

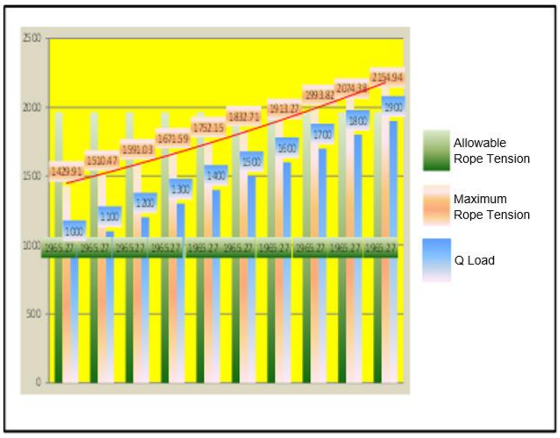


Figure 8. Analysis of Maximum Stress against Allowable Stress

From Figure 7, it can be observed that the heavier the total load, the greater the maximum stress generated on the steel rope [8].

3.4 Analysis of Allowable Rope Tension

"Equation (6)"

$$S = \frac{Pb}{K} \quad (6)$$

Where:
S = Pull on the rope, in kg
P = Rope breaking strength in kg
K = Safety factor (5.5)
Pb = 106 kn = 10808.99 kg

Table 4. SNI Steel Rope Standard [7]

Nominal Diameter (mm)	Minimum fracture load (kN) Zinc plated or no zinc plating Grade B	Weight Estimate (kg/m)
10	67,7	0,440
11	84,9	0,552
13	106	0,688
14	133	0,863
16	173	1,13
18	219	1,43
20	271	1,76
22	340	2,21
25	423	2,75
28	531	3,45
30	609	3,96
32	672	4,37
34	760	4,94
36	853	5,55
38	952	6,19
40	1080	7,04
42	1220	7,95
45	1370	8,91
48	1530	9,93
50	1690	11,0
53	1900	12,4
56	2120	13,8
60	2440	15,8

NOTE 3
Nominal diameter of steel wire rope construction:
- 6 x Fi(29) IWRC minimum 10 mm
- 6 x WS(31) IWRC and 6 x WS(36) IWRC minimum 20 mm
- 6 x WS(41) IWRC minimum 30 mm

Rope diameter (d) = 13 mm
Rope weight (W) = 0.06 kg/m
Breaking load (Pb) = 10808.99 kg
Fracture stress (σb) = 130 to 160 kg/mm2

Allowable Rope Stress Analysis With Broken Load steel rope specification 6 x FI (29), with a rope diameter of 13 mm

S = Pb/K

S = 10808.99 kg / 5.5
S = 1965.270 kg

So the allowable stress is:

S = 1965.270 kg

3.5 Allowable Rope Tensile Stress Analysis

"Equation (7)"

$$\sigma \sum = \frac{\sigma\, b}{K} \quad (7)$$

So the allowable tensile stress is

σ∑ = 160 / 5.5

σ∑ = 29.09 kg/mm^2

3.6 Number of Curves in the Rope and Dmin/d Rasio

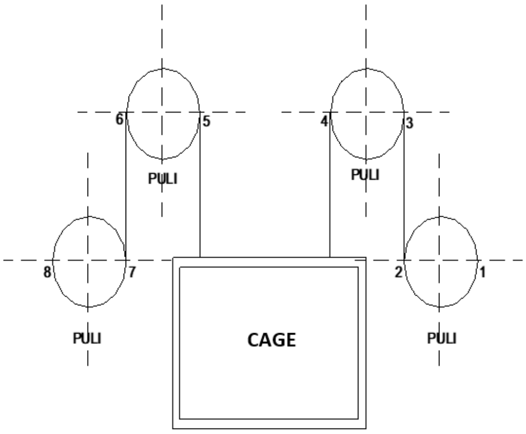


Figure 9. Number of Arches on the Rope and Rasio

“Equation (8)”

$$NB = \frac{Z}{2} \tag{8}$$

NB = 8 / 2
NB = 4

Table 5. Analysis of Maximum Stress against Allowable Stress

number of arches	Dmin/d	number of arches	Dmin/d	number of arches	Dmin/d	number of arches	Dmin/d
1	16	5	26.5	9	32	13	36
2	20	6	28	10	33	14	37
3	23	7	30	11	34	15	37.5
4	25	8	31	12	35	16	36

Thus:

Dmin / d = 25

3.7 Steel Rope Cross-Sectional Area Analysis

“Equation (9)”

$$F_{(174)} = \frac{S}{\frac{\sigma b}{K} - \frac{d}{dMIN} \times 50000} \tag{9}$$

Where:
S = Maximum pull on rope, in kg
σb = Tensile stress 160kg/mm^2 =16000kg/cm^2
K = Safety factor (5.5)
d/dMIN = 1/25

Thus:

$$F_{(174)} = \frac{S}{\frac{16000}{5.5} - \frac{1}{25} \times 50000}$$

$$F_{(174)} = 1{,}54\ cm^2$$

3.8 Analysis of Tensile Stress at Maximum Steel Rope Pulls

“Equation (10)”

$$\sigma t = \frac{Sb}{F_{(174)}} \tag{10}$$

Where:

Sb = Maximum pull on the rope
Sb = 1401.35 kg
F(174) = 1.54 cm^2

$$\sigma t = \frac{1401.35\ kg}{1.54\ cm^2}$$

$$\sigma t = 9.09\ kg/cm^2$$

Thus the maximum tensile stress is

σt = 9.09 kg/cm^2

3.9 Steel Rope Diameter and Puly Diameter

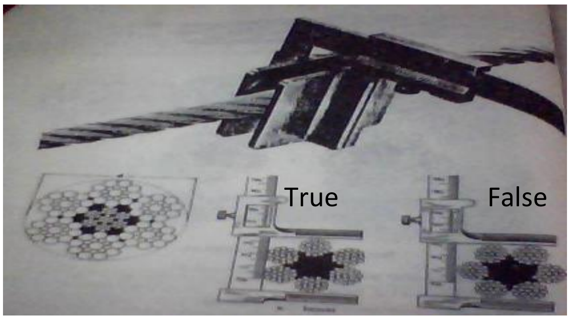


Figure 9. How to Measure the Diameter of Steel Rope

Given steel rope diameter = d = 13 mm
Given puly diameter = D = 200 mm

3.9.1 Analysis of Steel Rope Life

“Equation (11)”

$$A = \frac{D}{d} = m \times \sigma \times C \times C1 \times C2 \tag{11}$$

A = D/d ratio of drum or pulley diameter to rope diameter

m = A factor that depends on the number of repeated bends in the rope z during the wear period until the rope breaks.
σt = Thus the maximum tensile stress of 9.09 kg/mm2
C = Factor characterizing the rope construction and maximum tensile strength of the wire material = 0.93

C1 = Factor depending on the rope 0.93
C2 = Rope fiber material factor 1.37

Thus:

A = D/d = m x σ x C x C1 x C2
A = 200/13 = m x σ x C x C1 x C2
m = A / σ x C x C1 x C2
m = 15.3/9.09 x 0.93 x 0.93 x 1.37
m = 1.42

Table 6. Factor Price m [6]

FACTOR PRICE m									
Z is in thousands	30	50	70	90	110	130		150	
m	0.26	0.41	0.56	0.7	0.83	0.95		1.07	
Z is in thousands	170	190	210	230	255	280	310		340
m	1.18	1.29	1.4	1.50	1.62	1.74	1.87		2.09
Z is in thousands	370	340	450	500	550	600	650		700
m	2.12	2.27	2.42	2.60	2.77	2.94	3.10		3.17

3.9.2 Number of bends allowed

"Equation (12)"

$$Z_1 = a \times Z_2 \times N \times \beta \qquad (12)$$

N = Z_1/a x Z_2 x β
N = 210000 / 1000 x 4 x 0.5
N = 210000 / 2000
N = 105 Months
N = 8 Years 7 Months

4. Analysis and Discussion

From the results of the analysis with calculations, for the specifications of the Hoist and Steel Rope mentioned above, they are already in qualified criteria, in terms of safety.

1. Analysis of Total Load on Goods Elevator, Q total = 2662.5 kg
2. Analysis of Train Cage Weight, WO Cage = 581.25 kg
3. Weight Analysis of Cage Weight, Cage = 1081.25 kg
4. Analysis Diameter of one wire or δ = 0.65 mm
5. Maximum Steel Rope Stress Analysis, S = 1401.35 kg
6. Analysis of Tensile Stress at Maximum Steel Rope Pull, σt = 9.09 kg/cm^2
7. Allowable Rope Stress Analysis, S = 1965.270 kg
8. Analysis of Allowable Rope Tensile Stress, σ∑ = 29.09 kg/mm^2
9. Steel Rope Life Analysis, N = 8 Years 7 Months

5.1 Conclusion

1. At a total load on the elevator of 2662.5 kg, the hoist used capacity of 3 tons in the safe point Q total 2662, 5 kg (2.6 tons) < 3000 kg (3 tons), safety tolerance of 11.25%.
2. At maximum stress S = 1401.35 kg, smaller than allowable stress S = 1965.270 kg, safety tolerance 28.69%
3. At maximum fracture load is P = 7864.52 kg, smaller than the allowable fracture stress of SNI standard (Pb) = 10808.99 kg, safety tolerance 27.24 %
4. In the tensile stress on the maximum steel rope pull σt = 9.09 kg/cm^2, smaller than the allowable tensile stress σ∑ = 29.09 kg/mm^2, the tensile stress safety tolerance is 68.75%.

5.2 Recommendations

1. To extend the life time of the steel rope, it is recommended that the routine for checking and preventive maintenance such as lubrication of steel ropes, checking construction bolts and so on be carried out regularly.
2. Making Standard Operating Procedures so that the load limit does not exceed one ton in operation.
3. The addition of safety equipment can be done, on the elevator, such as a load cell and notification or buzer if the load is excessive.

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