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Araştırma Makalesi
Research Article

Computer aided design of chain elavator

Zincirli elevatörün bilgisayar destekli tasarımı

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Abstract: In this study, a computer program has been developed for the computer-aided design of single-strand chain elevators, which carry powder, bulk, and piece materials and have a wide range of applications. In industry or other usage areas, the most common single-strand chain, gravity tensioned, pre-bedded, bucket elevator is dimensioned using accepted coefficients, tables, catalogs, and formulas. The drive system includes an electric motor, gearbox, bearing, shaft, sprocket, sprocket hub, chain, bucket, and drive upper and lower body enclosure. Brands such as Nord, Yılmaz, Remas, and Flender are used as gearboxes, while brands such as SKF and FAG are used for bearings. In our calculations, a computer program has been developed based on the technical specifications of Remas for the gearbox and SKF for the bearings. Through the use of computer-aided design for the chain elevator, time loss and the burden of the design process were significantly reduced. This study has led to the identification of optimal design values, which in turn has lowered design costs. Operating costs were also minimized by avoiding design errors.

Keywords: Elevator, Design by Classical Method, Bucket Conveyors

Özet: Bu çalışmada, toz, dökme ve parça malzemeleri taşıyan ve geniş bir uygulama alanına sahip olan tek sıra zincirli elevatörlerin bilgisayar destekli tasarımı için bir bilgisayar programı geliştirilmiştir. Sanayi veya diğer kullanım alanlarında en yaygın kullanılan tek sıra zincirli, yerçekimi ile gerilimli, önceden döşenmiş, kovalı elevatör, kabul edilen katsayılar, tablolar, kataloglar ve formüller kullanılarak boyutlandırılmıştır. Tahrik sistemi elektrik motoru, dişli kutusu, yatak, mil, dişli çarkı, dişli göbeği, zincir, kova ve tahrik üst ve alt gövde muhafazasını içerir. Dişli kutusu olarak Nord, Yılmaz, Remas ve Flender gibi markalar kullanılırken, yataklar için SKF ve FAG gibi markalar kullanılmaktadır. Hesaplamalarımızda, dişli kutusu için Remas'ın teknik özelliklerine ve yataklar için SKF'nin teknik özelliklerine dayalı bir bilgisayar programı geliştirilmiştir. Zincir elevatörün bilgisayar destekli tasarımı sayesinde zaman kaybı ve tasarım sürecinin yükü önemli ölçüde azaltılmıştır. Bu çalışma, optimal tasarım değerlerinin belirlenmesine yol açmış ve tasarım maliyetlerini düşürmüştür. Ayrıca, tasarım hatalarından kaçınarak işletme maliyetleri de en aza indirilmiştir.

Anahtar Kelimeler: Elevatör, Klasik Metot ile Tasarım, Kovalı Konveyörler

1. Introduction

An elevator is a mechanical conveying equipment used for vertically transporting materials from one point to another. It is particularly useful for conveying bulk materials such as dust and granules that need to be transported vertically in large quantities. Elevators are highly efficient and widely used vertical conveying systems for a variety of materials, making them one of the most popular vertical transportation systems in today's world. Therefore, their usage areas are very widespread.

The design of chain elevators may seem easy at first glance. Because it can be thought of as stretching the segments between two toothed segments of an endless chain, taking the material from the loading mouth, raising it to the desired point and unloading the material from the pouring mouth. However, as calculations reveal, the process is far from simple. Designing chain elevators involves extensive use of charts, tables, experience, and predictions. A single incorrect value in these long and complex calculations can significantly alter the results, and designing for a different material with the same capacity and height requires restarting the entire process.

2. Source Research

In Kurtboğan's (2006) study, speed is stated as the most important design criterion for bucket elevators. It is noted that speed causes both the dimensions and costs of the elevator to increase excessively. The diameter of the drum or gear is also highlighted as a crucial factor in elevator design. It is observed that while an increase in the drum or gear diameter results in smoother transmission, excessive growth in diameter leads to an increase in

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the elevator's volume. Therefore, experimental standard tables are required to be used for the selection of both speed and drum diameter in practice.

It was mentioned that for the transmission of relatively hard, coarse-grained materials (such as ore) at high temperatures, a chain elevator should be preferred, while for the transmission of powdered materials (especially grains) at high speeds, a belt elevator should be preferred (Kurtboğan, 2006). The traction elements of elevators were extensively examined in this study, and their characteristics were analyzed. It was stated that the correct selection of either chain or belt should be made based on environmental conditions and material properties. Standards determine almost all elements in elevator design, and it was noted that smooth transmission would be achieved by utilizing these values in the design.

In the study by Gerdemeli (1996), the types and parts of bucket elevators were defined. Information on loading and unloading the elevator based on the characteristics of the transported material was also provided. It was mentioned that materials such as coal dust, cement, powder, soil, and slate, which have small particles, dust, and moderate abrasiveness, would not resist scooping during loading, making the scooping method suitable for conveying such materials. However, for materials with large particles, coarse and abrasive properties, such as gravel, ore, and large coal, which would resist scooping during loading, it was emphasized that direct feeding to the buckets, bypassing scooping, should be employed. Regarding the emptying of the buckets, different emptying types were mentioned depending on material properties and elevator speed. It was also stated that almost all elements in the design of bucket elevators are determined by standards, and theoretical calculations can be made using these values in the design process.

In the study of Cerit (1984) it was mentioned that various types of powder, granular, and bulk materials (such as cement, sand, soil, peat, coal, soda, refractories, chemicals, grain, flour, etc.) and building materials are conveniently transported using elevators. It was noted that elevators are employed in chemical industry factories, foundries, refractory material production, metallurgical factories, food industry, flour mills, grain silos, and similar settings. The characteristics of elevator components were described, and the calculation method for elevator design was explained using tables with standards determined for elevator types and their components.

In the study of Demirsoy (1984) the elevator as a mechanism that operates either vertically or inclined and includes a band and a chain as the traction organs was defined. It was mentioned that elevators are distinguished primarily by their methods of feeding and discharging buckets. Types that use centrifugal force for rapid discharge and types that operate more slowly due to the weight of the conveyed material were discussed. Additionally, important DIN standards related to elevator design were provided.

In the study of Güven (1997), a computer-aided design of rubber band conveyors was made. The history of rubber belt conveyors, their applications from the past to the present, the types of bulk materials they can transport, and the various types of rubber belt conveyors were discussed. The benefits of using computer-aided design, particularly with the Visual Basic 3.0 programming language, for the ergonomic design of conveyors in terms of workload and time efficiency were emphasized.

In the study of Karagülle (2004) an effort was made to generate interest in the language among programmer candidates by developing two very simple yet useful examples for an introduction to visual programming. The structure of the programming language, variables, data types, loops, program control expressions, operators, mathematical operations, functions, subprograms, object-oriented programming, and debugging issues were explained.

In the study of Demirli and İnan (2006) an attempt was made to explain screen windows for an introduction to visual programming, the basics of programming, recommendations for programmer candidates, assignment procedures, functions and procedures, loops, and error handling procedures.

3. Method

For the computation of a single-strand chain elevator and the dimensioning of its components in a computer environment, Visual Studio C# (C Sharp) 2017 Programming Language was utilized. This programming language is designed for creating various applications running on the .NET Framework in the Windows environment. It is an object-oriented programming language (Aktaş, 2014).

4. Program Phases

The window created as the main menu, where program data is entered and outputs are obtained, serves as the entry page of the program. Figure 1 displays the main window that has been created.

When the calculation icon is clicked on the main window of the program, it switches to the program writing page where the desired information is calculated as blank spaces in the parts shown in the form of empty boxes in Figure 1. The command back-end, where the program calculation is performed, is where the desired program is created line by line. After all the operations are completed, when the program is executed, the window view appears on the screen. The required inputs on this screen are: capacity, material to be transported, conveying distance, selection of one of the materials defined as AISI4140-AISI4340-AISI5140 for the drive shaft material, and selection of one of the materials defined as AISI1035-AISI1040-AISI1045-AISI1050 for the chain material.

In Figure 2, the result view of the main window is shown at the top. Here, fundamental values such as capacity, shaft distance, bucket type and quantity, reducer type and power, reducer shaft diameter, bearing type and shaft diameter, chain type and length, chain sprocket diameter and speed are displayed on the screen as output results. Additionally, this screen includes icons showing chain characteristic values, the overall appearance of the elevator, and shaft sizing. When the shaft sizing button is clicked, the visual structure of the shaft along with numerical values is displayed on the screen as shown in Figure 3, which illustrates the drive system shaft sizing visualization. Clicking on the chain properties button will display the chain characteristic values table on the screen as shown in Figure 4. When the general appearance but-

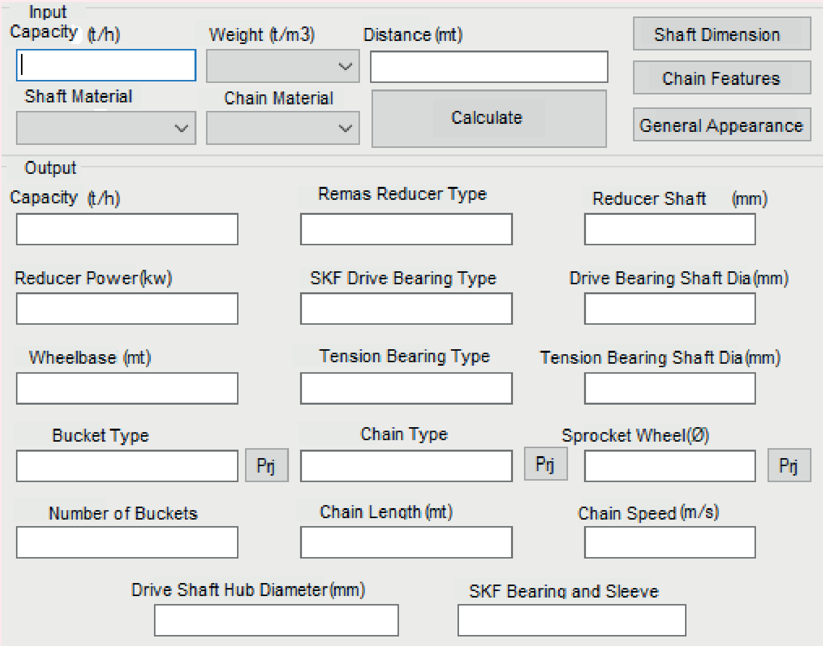

Figure 1. Program main window

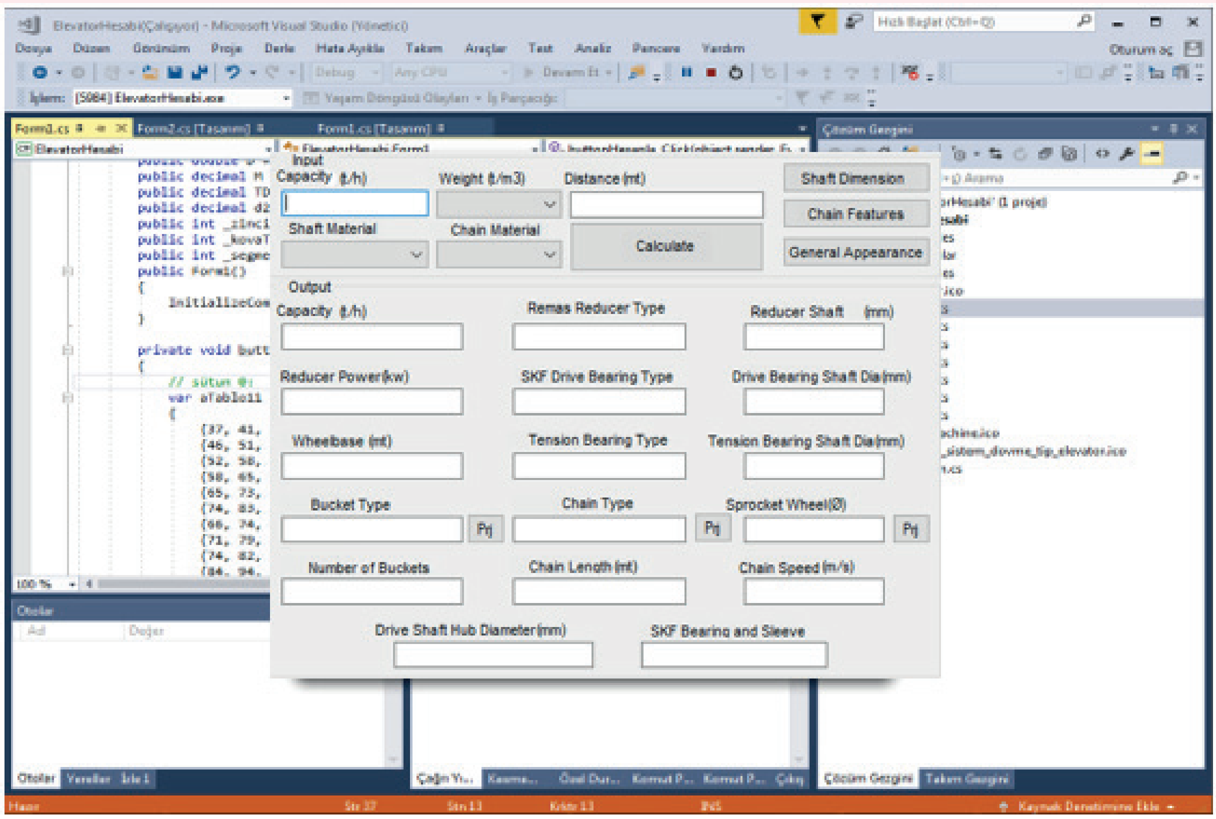

Figure 2. Microsoft visual studio c# program main window

ton is clicked, the parts constituting the elevator and the general appearance are displayed on the screen. Clicking on the Project button, located next to the bucket type output, chain type output, and chain sprocket output, will display the project drawing details on the screen.

4.1. Material Selection

Computer-aided elevator calculations have been performed for materials such as clinker, coal, cement, farina, ground limestone, slag, fly ash, limestone, sand, salt, and coke. By selecting the name of the material from the dropdown menu, the program obtains the specific gravity value of the material from the table and includes this value in the calculations.

4.2. Capacity Selection

In the selection of capacity, the capacity table shown in Figure 5, obtained through practical applications, experiences, and tests, has been utilized. The capacity values in this table have been incorporated into the program. The capacity values highlighted in yellow represent the most suitable ergonomic capacity values created considering operating conditions and material properties. Selection can also be made from capacity values without color, but here, the program prompts the selection based on the ergonomic capacity value. If the desired capacity value exists, it is selected; otherwise, the closest higher capacity value is chosen. If there are multiple capacity values for the higher capacity, the program ensures the selection of the capacity value where the drum speed is lower, considering the physical installation location of the elevator and, most importantly, the operating conditions. From the location of the selected capacity value, the bucket type and volume, chain type and pitch; and from the vertical columns, chain sprocket diameter and speed parameters are selected. Based on these parameters, the capacity is calculated in tons per hour (t/h) using equation (1).

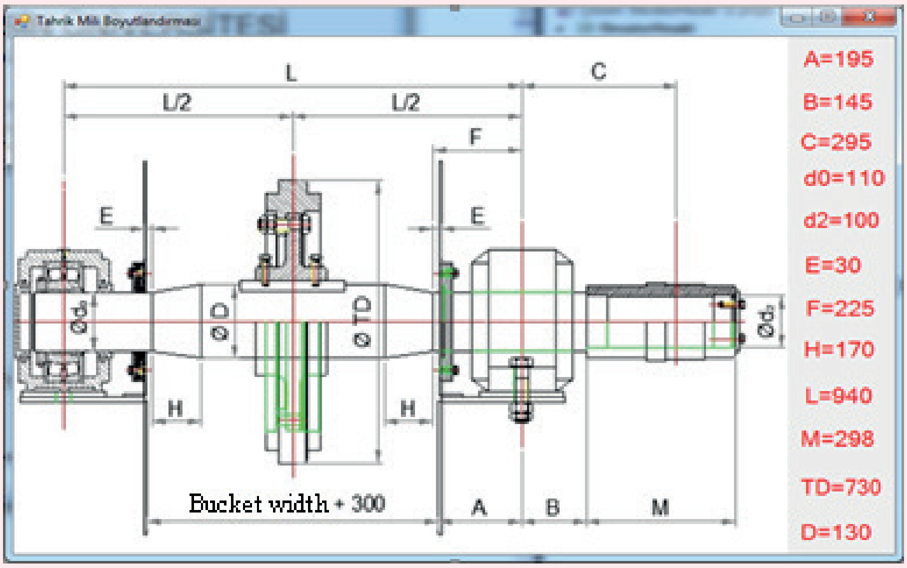

Figure 3. Drive system shaft dimensioning as a result of the calculation

ELEVATOR CHAIN CHARACTERISTIC DIMENSIONS AND METALLURGICAL VALUES														
MODEL	OUTER BUCKET CHAIN mm B:Groos W(kg)	CENTRAIL BUCKET CHAIN mm N:Net W(kg)	PITCH DIAMETER mm	INNER PITCH DIAMETER mm	PITCH LENGTH mm	PIN DIAMETER mm	PIN LENGTH mm	PIN AXIS mm	BUCKET CON. HOLES AXIS mm	BUCKET CON. HOLES DIAMETER mm	PITCH MATERIAL	PITCH STRENGTH mm	PITCH CLASS HARDNESS	PIN HARDNESS DEPTH mm
A1	110 x 10 x200 B 1,760 N 1,450	60 x 10 x 215 B 1,032 N 0,800	Ø38,20	Ø22,70	71	Ø22,20	100	140	100 x 100	Ø14	8620	2,0 2,2	4140 28-32 HRC	2,4-2,8 58-62HRC
B3	150 x 12 x 240 B 3,456 N 2,540	75 x 12 x 260 B 1,872 N 1,340	Ø44,68	Ø26,18	95,20	Ø25,90 Ø25,40	139	152,4	200 x 130	Ø18	8620	2,2 2,4	4140 28-32 HRC	2,8-3 58-62HRC
B4	155 x 14 x 245 B 4,253 N 3,180	85 x 14 x 260 B 2,475 N 1,740	Ø50,68	Ø29,38	99,20	Ø29,10 Ø28,60	147	152,4	200 x 130	Ø18	8620	2,4 2,6	4140 28-32 HRC	3-3,2 58-62HRC
B5	155 x 16 x 270 B 5,356 N 4,260	85 x 16 x 290 B 3,155 N 2,300	Ø50,68	Ø29,38	103,20	Ø29,10 Ø28,60	155	177,8	200 x 150	Ø18	8620	2,6 2,8	4140 28-32 HRC	3,2-3,4 58-62HRC
$ 06	95 x 18	95 x 18	Ø58,10	Ø36,80	112	Ø36,10	193	177,8	284 x 250		8620	2,6 2,8	4140 28-32 HRC	4-5 58-62HRC
$ 13	95 x 18	95 x 18	Ø58,90	Ø40,50	127	Ø39,70	206	177,8	300 x 150		8620	2,6 2,8	4140 28-32 HRC	4-5 58-62HRC
$ 15	105 x 20,5	105 x 20,5	Ø70,90	Ø44,70	132	Ø44,10	230	177,8	300 x 150			2,6 2,8	4140 28-32 HRC	4-5 58-62HRC

Figure 4. Chain characteristic values used in the calculation

$$\frac{3600(s/h)*BucketVolume(dm^3)*SpecificWeight(t/m^3)*0.75*V(m/s)}{BucketPitch(mm)} \quad (1)$$

The calculated capacity is compared with the desired capacity. If the result of the comparison is smaller than the desired capacity, then another capacity value, which is the closest higher value, is selected. If the result of the comparison is equal to or greater than the desired capacity, the process proceeds to the next stage.

4.3. Reducer Power Calculation

The reducer power Kw is calculated from the following equation taking into account the selected capacity value and the entered shaft distance.

$$\frac{Capacity(kg/s)*9{,}81*wheelbase(m)*Coefficient(2,....2{,}5)}{1000} \quad (2)$$

The coefficient expressed in equation (2), with values ranging from 2 to 2.5, is selected by the program based on the applied capacity in practice. In the Turkish market, there are reducer companies such as Nord, İmak, Yılmaz, Remas, and Öztekfen. Remas brand reducer data has been used as the basis for the creation of the program. The reducer types and hydraulic coupling type are selected by the program based on the reducer power from the reducer catalog (Remas catalog, 2017). Bearing type, bearing shaft diameter, bearings, sleeves, and corresponding tensioning shaft diameters and tensioning bearings are obtained by the program from the SKF catalog (SKF catalog, 2017)

4.4. Chain Length Calculation

The calculation of chain length (CL) is done using equation (3). The accuracy of the chain length is verified through the calculation of the number of buckets. The number of buckets is calculated from equation (4).

CL = Wheelbase x 2(mm)+Chain sprocket Circumference(mm)+Chain Bushing Circumference(mm) (3)

$$\text{Number of Buckets} = \frac{ChainLength(m)}{BucketPitch(m)} \quad (4)$$

If the number of buckets turns out to be an odd or fractional number, it is taken as the nearest even integer value. Then, the actual chain length is determined by multi-

CHAIN			BUCKET					CHAIN GEAR DIAMETER AND SPEED					
Type	Weight (Kg/mt)	Bushing diameter (mm)	Type	Width	Volume (dm^3)	Weight (kg)	Pitch	1,04 Ø655	1,16 Ø730	1,25 Ø790	1,4 Ø890	1,56 Ø1005	1,67 Ø1115
A1 CHAIN	22	38,2	210	200	3,7	5,8	280	37	41	45	50	56	60
				250	4,6	6,6	280	46	51	55	62	69	74
				280	5,2	7,3	280	52	58	63	70	78	84
				315	5,8	7,8	280	58	65	70	78	87	93
				355	6,5	8,7	280	65	73	78	88	98	105
				400	7,4	9,9	280	74	83	89	100	111	119
B3 CHAIN	40	44,68	250	280	7,2	9	305	66	74	80	89	99	107
				300	7,7	9,7	305	71	79	85	95	106	114
				315	8	10,2	305	74	82	89	99	111	118
				355	9,1	11,1	305	84	94	101	113	126	135
B4 CHAIN	45,5	50,68		400	10,3	12	305	95	106	114	128	142	152
				450	11,6	13	305	107	119	128	144	160	172
				500	12,9	14	305	119	133	143	160	178	191
				560	14,4	16,2	305	133	148	159	179	199	213
B5 CHAIN	47,5	50,68	285	400	16,8	16,8	356	133	148	159	179	199	213
				450	18,9	18	356	149	166	179	201	224	240
Ş06 CHAIN	62,5	58,1		500	21	19,9	356	166	185	199	223	249	266
				560	23,5	22,5	356	186	207	223	250	278	298
				630	26,4	24,5	356	208	233	251	281	313	335
Ş13 CHAIN	65	58,9		710	29,8	25,4	356	235	262	283	317	353	378
				800	33,6	32,6	356	265	296	319	357	398	426
				900	37,8	33,3	356	298	333	359	402	448	479
Ş15 CHAIN	82,5	70,9		1000	41,9	42,5	356	331	369	398	445	496	531
				1100	46,2	46,02	356	365	407	438	491	547	586

CAPACITIES ACCORDING TO BUCKET TYPE AND CHAIN GEAR DIAMETER.

m^3/ h (% 75 CONSIDERED AS FULL.)

Figure 5. Capacities by bucket type and sprocket diameter

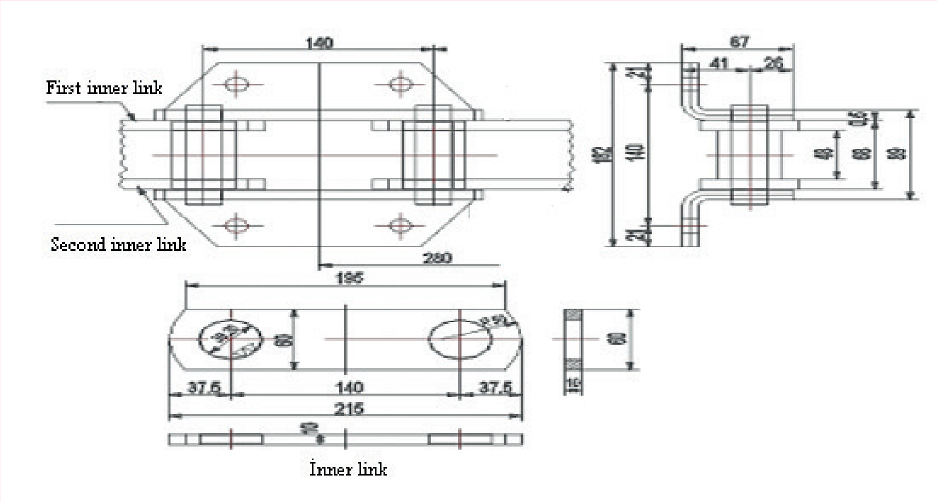

Figure 6. A1 chain view and inner link section

plying the number of buckets by the bucket pitch.

4.5. Chain Link Section Calculation

To select the chain material in the program, the material name is chosen from the dropdown menu on the main window. This action allows the program to obtain the material's breaking strength value and include it in the calculations. In the program, chain views and inner link sections for A1-B3-B4-B5-Ş06-Ş013-Ş15 chains have been processed. Figure 6 displays only the A1 chain view and inner link section drawing detail.

Minimum total cross-sectional areas at pea-pin connection of the chain types shown in the main window result form are determined from the AutoCAD project drawing for the pea cross-sectional areas of the selected chain types. These values are taken by the program according to the chain types from the generated table. If a tensioning system weight project has been drawn, the project weight is entered. If there is no project drawing, an average weight should be entered into the program.

4.6. Drive Shaft Diameter Calculation

Figure 7 illustrates the forces acting on the drive shaft. These forces cause shear, bending, and torsion in the shaft. T_1 represents the weight of the material-filled side (N), T_2 represents the weight of the material-empty side (N), and D represents the shaft hub diameter (m).

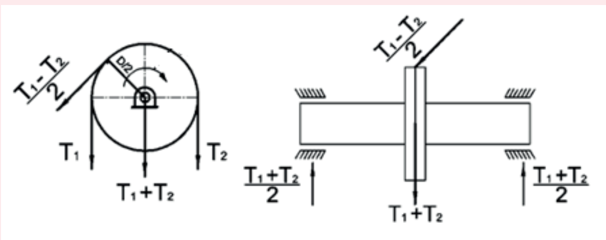

Figure 7. Force distribution on the drive shaft

The bending moment Me (Nm) occurring in the shaft is calculated from equation (5), where L represents the length in meters (m). The torsional moment Mb (Nm) occurring in the shaft is determined from equation (6).

$$M_e = \frac{(T_1 + T_2) \times L}{4} \quad (5)$$

$$M_b = \frac{(T_1 - T_2) \times D}{4} \quad (6)$$

The torsional moment M_d (Nm) occurring in the shaft is calculated from the following equation. N is the power transmitted by the motor (kW), n is the speed of the motor (revolutions per minute, rpm), and η is the power transmission efficiency from the motor to the gearbox. For the shaft to be able to perform the rotation process, M_d must be greater than or equal to M_b.

$$M_d = 9550 \frac{N}{n} \quad (7)$$

The shaft diameter D (m) under dynamic loads is calculated from equation (8) considering the Maximum Shear Stress Hypothesis (MSSH). Equation (9) represents the shear safety stress.

$$D \geq \sqrt[3]{\frac{2 \times 16}{\pi \times \sigma^*_{em}} [\sqrt{(M_e \times K_m)^2 + (M_b \times K_t)^2}\,]} \quad (8)$$

$$\tau^*_{em} = (\sigma^*_{em})/2 \quad (9)$$

The shear safety stress of the shaft is calculated from equation (10) for infinite life under fully variable loading due to dynamic loads during system start-up and shutdown (continuous stress state).

$$\tau^*_{em} = \frac{K_y \times K_b}{\beta_k \times S_2} \tau_{em} \quad (10)$$

A working factor of 2 is taken for the dynamic effects for the working factor S_2. The program obtains the size factor (K_b) value from the table created according to the diameter, the notch sensitivity factor (β_k) value from the table created according to the material, and the surface factor (K_y) value from the table created according to the material's tensile strength (Bozacı, 2005). The program obtains the impact (Km) and wear (Kt) coefficients applied to the bending and torsional moments for rotating shafts from the table created according to the loading condition (Aşık, 1992).

5. Discussion and Conclusion

In order to carry out the engineering design of a single-strand chain elevator using the classical method, the designer calculates values by relying on experience, practical applications, tables, charts, and catalogs. When selecting from Figure 5 for conveying cement with a specific gravity of 1 t/m³ at a capacity of 100 t/h and a height of 30 m, the designer may make different choices. By se-

Table 1. Input preferences of design criteria

	I Preference	II Preference	III Preference
Capacity(m³/h)	99	101	106
Chain type	B3	B4	B4
Sprocket Wheel(mm)	Ø890	Ø790	Ø730
Chain speed(m/s)	1.4	1.25	1.16
Bucket type	250 x 315	250 x 355	250 x 400

Table 2. Comparison of calculation results

Situations	I Preference	II Preference	III Preference	Program result
Capacity	99.21 t/h	101 t/h	106 t/h	100.76 t/h
Chain type	B3	B4	B4	B4
Chain length	62.789 m	62.789 m	62.179 m	62.789 m
Sprocket wheel	Ø 890 mm	Ø 790 mm	Ø730 mm	Ø 790 mm
Chain speed	1.4 m/s	1.25 m/s	1.16 m/s	1,25 m/s
Bucket type	250 x 315	250 x 355	250 x 400	250 x 355
Number of buckets	206 Ad	206 Ad	204 Ad	206 Ad
Reducer power	16.22 Kw	17.29 Kw	17.29 Kw	18,5 Kw
Reducer type	/ K2A-225	/ K2A-225	/ K2A-225	/ K2A-225
Distance between bearing	L : 1035 mm	L : 1075 mm	L : 1120 mm	L : 1075 mm
Drive shaft	D : 14.72 cm	D : 15.11 cm	D : 15.83 cm	D : 160 mm
Drive of buckets	~150 mm	~150 mm	~160 mm	

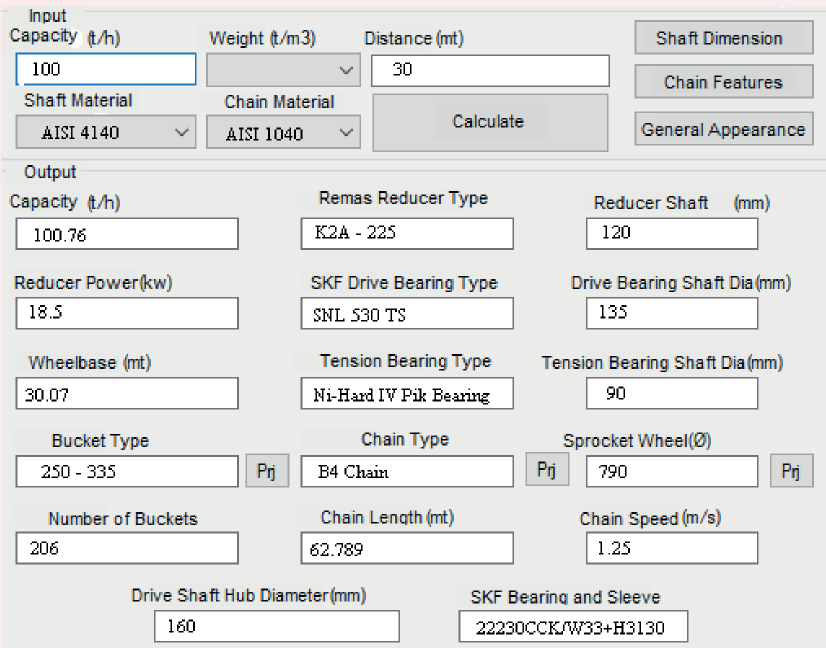

Figure 8. Calculation main window result form

lecting three different values from Figure 5, the designer can make a choice from the design criteria in Table 1 for their design. These differences will lead to changes in the elevator height, elevator length, and elevator weight.

In this study, by inputting the operation data into the software implemented and running the program, the main window result form depicted in Figure 8 is obtained.

The calculation results obtained by the classical method according to the preferences in Table 1 are compared with the values calculated by the program in Figure 8 in Table 2.

As a result, during the design process, it is crucial to have a thorough understanding of operating conditions and material properties, and the designer must be experienced. If two different individuals were to design an elevator with the same specifications using the classical method without knowledge of each other's work, they might arrive at different results. One of these results may be more ergonomic than the other. Another scenario is that designing for a different material at the same capacity and height would require starting all calculations from scratch. Designing with computer assistance would minimize time loss and design workload, reduce design costs by using optimal values, prevent erroneous designs, and consequently decrease operational and maintenance expenses.

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