Dec. 30, 1930.

J. H. EDWARDS ET AL

1,786,938

SERIES AND GROUPS OF I-BEAMS

Original Filed May 16, 1925

4 Sheets-Sheet 1

Fig. 1.

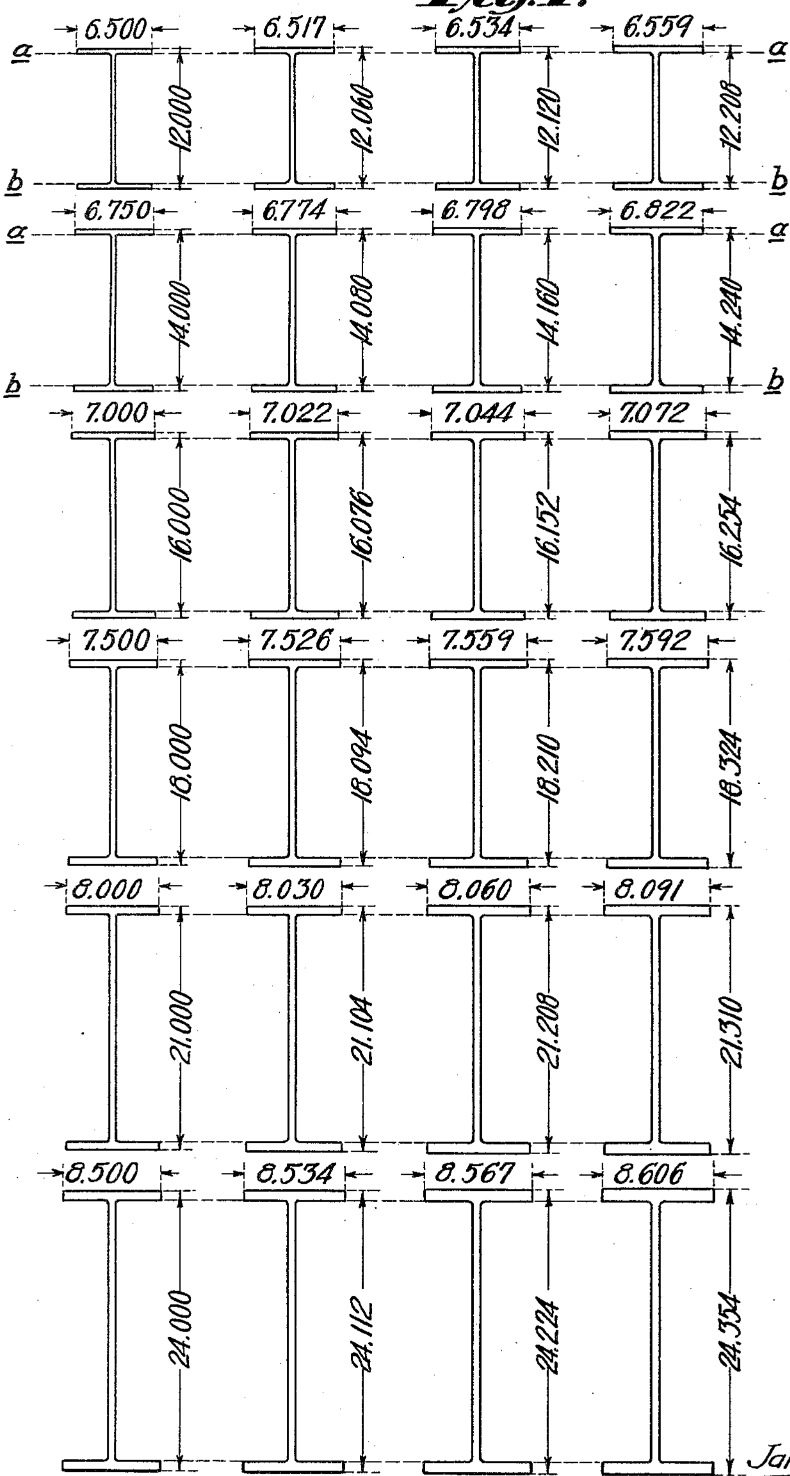

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Fig. 2.

Rounded Series		Geometrical Ratios →	Academic Series				
Col. 1	Col. 2		Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Depth	Wt. per Lin. Ft.		Depth	Wt. per Lin. Ft.		Depth by Weight	
			1.15	1.20		1.38	1.084
12	28		12.0	28.0		336	
	30				30.3		364
	32				32.9		395
	35				35.6		428
14	33		13.8	33.6		464	
	36				364		502
	39				39.5		545
	42				42.8		590
16	40		15.8	40.4		640	
	43				43.8		693
	46				47.4		751
	50				51.5		814
18	48		18.2	48.5		882	
	52				52.6		956
	57				57.0		1037
	62				61.8		1123
21	58		20.9	58.3		1218	
	63				63.2		1320
	68				68.5		1430
	73				74.2		1550
24	70		24.0	70.0		1680	
	76				75.9		1821
	82				82.2		1973
	89				89.1		2139

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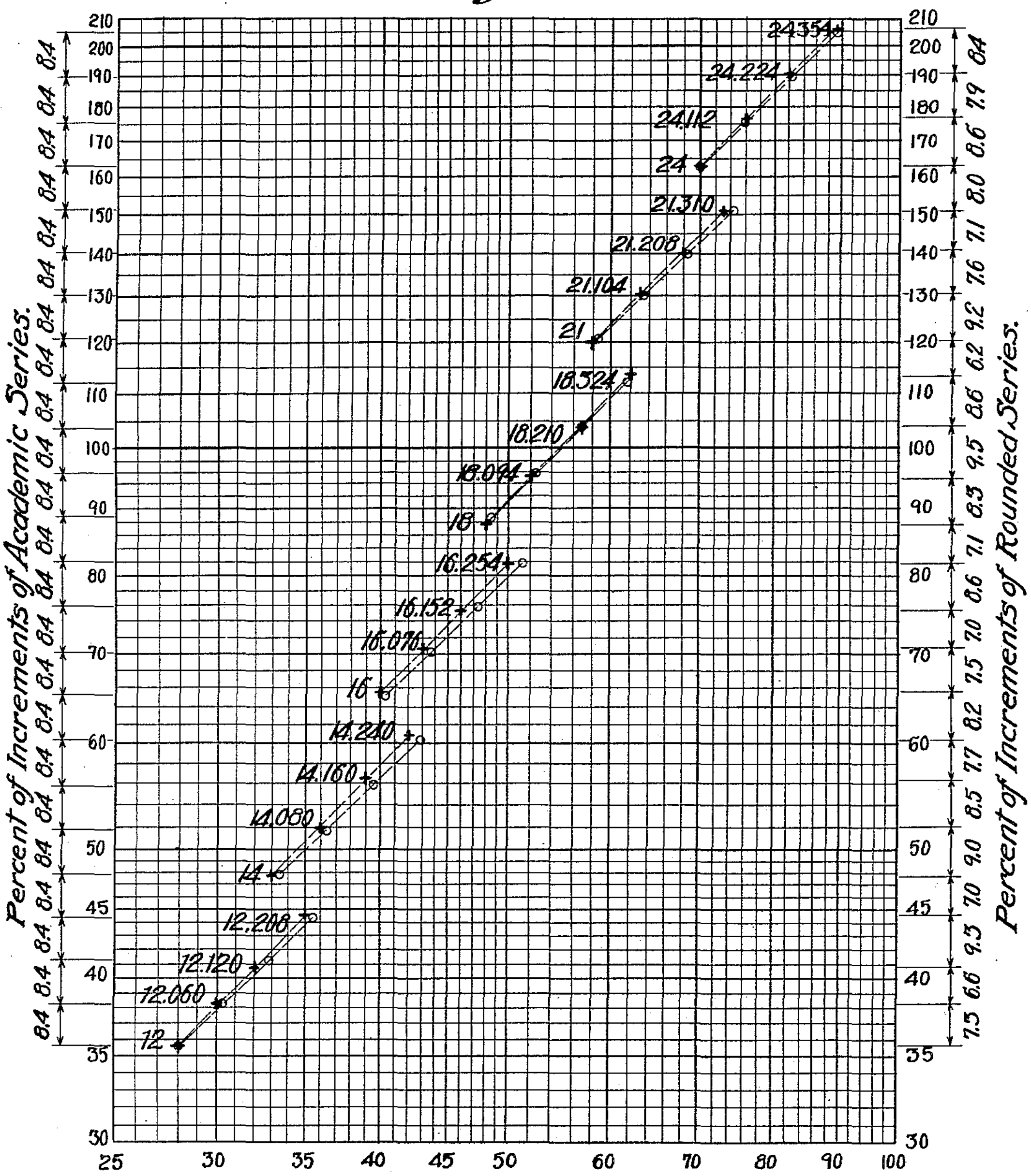
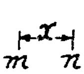
Fig. 3.





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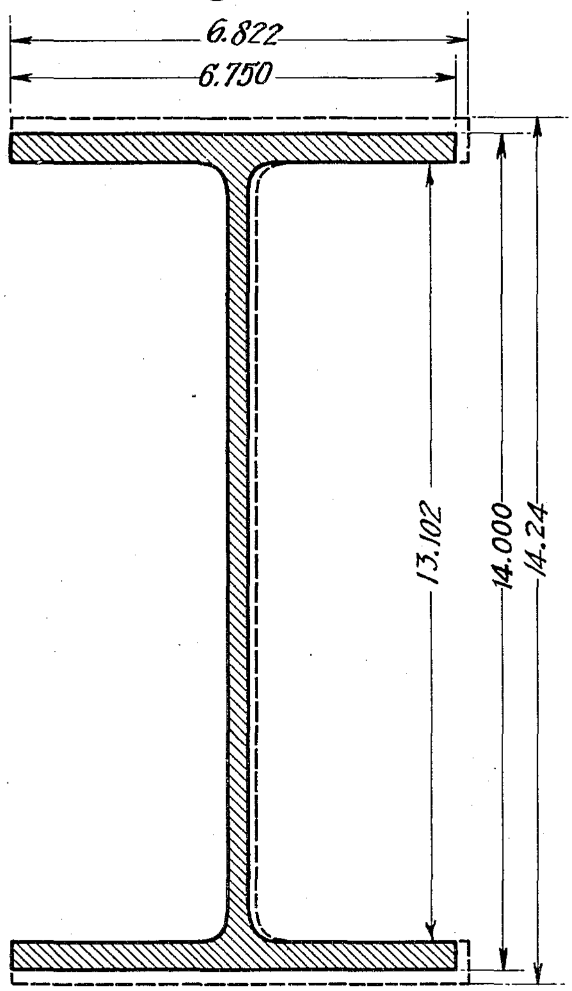
Original Filed May 16, 1925 4 Sheets-Sheet 4

Fig. 4.



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UNITED STATES PATENT OFFICE

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SERIES AND GROUPS OF I-BEAMS

Application filed May 16, 1925, Serial No. 30,688. Renewed September 21, 1929.

This invention relates to rolled structural sections and aims to provide a series of members whose sizes, weights and other properties progress in such an orderly predetermined manner that the requirements of the structural art and trade are met more efficiently, more conveniently and with fewer sections and fewer groups of sections than required in any series heretofore available.

The invention will be understood from the following description when read in connection with the accompanying drawings and tabulated data forming part of the specification.

In the drawings, Fig. 1 is a view showing a series of I-beams drawn to emphasize certain characteristics of the invention;

Fig. 2 is a table listing certain dimensions and other properties of the series of beams illustrated in Fig. 1;

Fig. 3 is a chart laid out to a logarithmic scale corresponding to that used on a standard ten inch slide rule, the chart showing graphically the orderly relationship of various characteristics of the several sections constituting the series illustrated in Figs. 1 and 2;

Fig. 4 is a cross-section of an I-beam represented at a reduced scale in full lines the size and contour of the lightest section of the 14 inch group and in dotted lines the contour and size of the heaviest section of the same group.

Throughout the specification and claims, we use the terms series and groups of sections and to clarify these terms we define them as follows. By a "series" we mean a set of sections covering a given range of depths or weights whose essential features progress in a predetermined orderly fashion. By the term "group" is meant two or more sections of substantially or approximately the same depth, preferably referring to the internal depth (distance between the inner faces of their flanges), and generally producible from one set of finishing rolls by a proper spacing of the rolls.

So far as we are aware there has never been produced a series of rolled I-beam sections whose sizes and other properties progress in the orderly manner which characterizes our invention. The difficulties in designing and commercially producing such a series are many. Theoretical rules for proportioning such sections are confronted by the varying and often conflicting conditions under which each section is called into service so that a section ideal for one purpose is inadequate or wasteful for another.

The various series of I-beam sections heretofore offered consist of groups whose essential features progress either irregularly or else by arithmetical increments containing many needless duplications at certain points of the range and an insufficient number of efficient sizes available at other points. They originated with the capacity of the mills at the time each group was adopted and as this capacity was broadened sizes were added in a haphazard, non-orderly fashion. The result is that there are now on the market an unnecessary profusion of available sections within certain ranges, and a deficiency of available sections in other ranges.

We have discovered, however, we believe for the first time in the history of the structural art, a principle which may be advantageously applied to the proportioning of individual sections whereby the availability of the sections comprising a series is broadened, their practical efficiency increased, their convenience enhanced. An important feature from a practical standpoint is that while our series gives a greater choice of sizes and strengths to meet varied requirements, we can produce the series with less equipment than is necessary to produce a collection of haphazard sizes in a similar range now available.

The design of a series of solid rolled I-beam sections differs from the design of built-up sections in that while the latter may be adjusted to comply with diverse requirements after such requirements have been determined the former must be designed prior to the determination of requirements. This is for the reason that the cost and delay that would accompany the preparation of special sets of rolls to suit each case would be prohibitive. Therefore, the ideal series of solid rolled sections is one that most economically anticipates all probable requirements.

The chief object of our invention is to replace the heterogeneous sizes and weights of I-beams now and heretofore produced, by a regular and consistent series based on our new principle of design that will with a minimum number of sections and rolls provide a choice of I-beams in any part of the series to economically suit various requirements.

In designing a structure it is customary to select the available weight of section whose strength comes within a given tolerance percentage of the strength required. Our invention embodies a new principle which consists in the application of a suitable geometrical progression to the successive depths and weights of a series of rolled sections so that their successive strengths progress by steps of approximately (but never in excess of) a given tolerance percentage. This enables a designer to select a section in any portion of the series that is within the allowed tolerance of his requirements and thus avoids the wasteful use of surplus material. Our series of sections is made up of convenient groups requiring a minimum number of sections producible from a minimum number of rolls.

It is well known in the structural art that when I-beam sections are consistently proportioned their strength to resist flexure in the direction of their depth is a function of their depth multiplied by their weight per linear foot. Under our invention we first determine a convenient series of depths that progress by a suitable geometrical ratio. We then assign to these respective depths practicable weights per linear foot that progress by a suitable geometrical ratio. Next, we form a group or groups of each depth comprising intermediate weight sections whose strengths increase by geometrical steps of approximately (but not over) the given tolerance percentage. This gives us a series that is academically ideal but which includes inconvenient fractional dimensions and weights. In order to adapt the advantages of this series to practical use we finally adjust the dimensions and weights to more conveniently rounded numbers, to the exigencies of the rolling mills and to fabrication requirements, and add certain features described below that enhance the desirability of the series.

A tolerance frequently used in design and in building codes is five percent over or under. This tolerance can evidently be best met by a series of strengths that progress by steps of approximately (but not over) ten percent. We show in Fig. 2 a table of sections designed to meet this case in which it will be noted that all the depths, weights and strengths progress by geometrical ratios. For purpose of illustration we adopt a 12 inch and a 24 inch depth as fixed points for the reason that these depths are so convenient and popular that they may be considered standard. Furthermore, they embrace the range in which the greatest demand occurs. We desire to progress in geometrical ratio from 12 to 24 by a number of steps that will approximate multiples of one inch. We have found that five such steps will accomplish this purpose very closely and we therefore preferably adopt five steps for this range. The ratio that each intermediate depth must bear to the depth next below is the fifth root of the quotient of 24 divided by 12, namely 1.15. The intermediate depths so determined are given in the third column of the table, Fig. 2. Similarly, we determine a geometrical progression of weights to correspond with these depths taking 28 pounds as the weight of the 12 inch depth of section and 70 pounds as that of the 24 inch as we have found that these weights accord with economical rolling mill practice. The ratio that each weight must bear to the weight of the depth next below is the fifth root of the quotient of 70 divided by 28, namely 1.20. These weights are given in the fourth column of the table.

As explained above, the strength of the sections now determined is a function of their depth multiplied by their weight per linear foot. Their strengths will therefore progress by the ratio of 1.15 multiplied by 1.20, namely, 1.38, that is to say each will be 38 percent stronger than the one next below. These strength factors are given in column six of the table. It is not feasible to divide this ratio (1.38) so as to get steps progressing by exactly 10 percent but we can closely approximate the desired ratio by inserting four steps (i. e. three intermediate weights) at each depth which will give strengths progressing by a ratio of 1.084, namely 8.4 percent. These strength factors are given in column seven of the table. As it is more desirable from a practical standpoint to secure these strengths by assigning suitable intermediate weights to the depths already determined rather than to add other intermediate depths, we divide the desired strength factors by the respective depths of the groups to which they belong and so determine the corresponding intermediate weights which are given in column five of the table.

In column one of the table, Fig. 2, are given the rounded depths in multiples of one inch that we prefer to use and in column two we similarly give the rounded weights per linear foot in multiples of one pound that we prefer to use it being noted that none of these rounded depths or weights differs from the exact academic figures given in columns 3, 4 and 5 by as much as 3 percent.

Reference to Fig. 1 will indicate to the eye the orderly relationship of the various sections in each group and also the relationship of the several groups of the series. In this figure the first horizontal row illustrates the beams of the 12 inch group tabulated in Fig. 2, the next row shows the 14 inch group and so on, the last row showing the section identified as the 24 inch group of the table. The parallel dotted lines *a* and *b* show that the nternal depth or distance between the inner faces the flanges is the same for all the sections of a given group.

Fig. 4 is a cross-sectional view on a reduced scale showing in full lines the contour and size of the lightest or minimum weight section of the 14 inch group and in dotted lines the contour and size of the maximum weight section of the same group. The two extreme sizes here shown are producible from the same rolls and of course various intermediate sizes can also be made by the same rolls from which these are produced. The intermediate sizes which we provide for this group are not illustrated in this figure as their showing would confuse the cut. The sizes of the intermediate sections are indicated in Fig. 1.

Reference to Fig. 4 will show that the external depth of the lightest weight section of the 14 inch group is fourteen inches, that its internal depth or in other words the distance between flanges is 13.102 inches and that the width across the face of each flange is 6¾ inches. The widths and depths of the other sections of the 14 inch group as shown by dimensions in Fig. 1, increase from these dimensions by orderly predetermined increments of such magnitude that a constant ratio of depth increment to width increment of not less than three to one is maintained. For example, the depths of the 14 inch group in Fig. 1 increase by .08 inch increments and the widths increase by .024 inch increments and the ratio of depth increment to width increment is, therefore, 3.33⅓ to one which is more than three to one. This ratio of three to one is always less than the ratio that twice the mean flange thickness bears to the web thickness in the minimum weight section of the group. In our judgment this ratio is the least that will produce efficient sections.

The other members of the other groups of sections bear a similar relationship. For example, in the 16 inch group the minimum weight section is sixteen inches deep and measures seven inches across each flange. The heavier weight sections of this group as indicated by the table also have weights per linear foot which increase at a substantially constant geometrical ratio and their depths and widths (like those of the other groups) increase by increments that have a substantially constant ratio of not less than three to one.

As stated above, we have designed our new series of sections in a systematic and accurate manner. In the table of Fig. 2, the properties on which the sections constituting our series are based is headed "Academic series". The depth of sections actually rolled and their weights per linear foot are tabulated under the heading "Rounded series". It is to be noted that the depth of section heading each rounded group is expressed in non-fractional units of (inches) and that the weights per linear foot are expressed in even multiples of one pound. That is to say, the weights are measured in whole pounds. This avoids the use of bothersome fractions and materially lessens the labor and mental fatigue involved and lessens the chance of error in figuring weights, strengths, costs, and so forth, the advantage of which will at once be appreciated by those skilled in this art.

The ratio chart identified herein as Fig. 3 shows graphically the close correspondence of the rounded series with the academic series tabulated in Fig. 2. This chart is laid out on a logarithmic scale corresponding to the graduations on a standard ten inch slide rule. The vertical ordinates indicate section moduli in inches cubed and the horizontal abscissas indicate weights per linear foot in pounds. The small circles (○) designate I-beam sections of the academic series and the crosses (+) locate the I-beam sections of the rounded series tabulated in Fig. 2. The oblique dotted lines connect the sections constituting respective groups which are producible each from one set of rolls.

Comparison of the relative position of the circles (○) and the crosses (+) will show at a glance how closely our rounded series approaches the academic series. At the left the steps between the several sections of the academic series is shown as 8.4 percent. The percentage of steps between the different sections of the rounded series is indicated at the right side of the chart. It will be noted that in no case does the latter exceed ten percent. The distance (x) laid off between the points m and n corresponds with the ratio of ten percent and can be used to scale off values on either the ordinates or abscissas in any part of the chart.

It is apparent from the above that in our series, in the range of depth from 12 to 24 inches inclusive, we have only six groups and twenty-four different weights of sections whose strengths progress by a ratio which never exceeds ten percent more than the next available section. Hence, it is clear that a section can be selected in any part of the series whose strength is within the desired tolerance of any practical requirement.

While we have described our invention by specific reference to I-beams ranging from 12 inches to 24 inches in depth, we, of course, can extend our series to include sections smaller than 12 inches and greater than 24 inches in deptht.

While not limited thereto the beams herein shown and described are particularly well adapted for use as joists.

By the term "joists" is meant beams whose primary purpose is to receive the direct load on a structure. They are sometimes called "filling-in beams". One of their essential characteristics is that in order to keep down their weight and also to permit of neat architectural finish, their flanges should be moderately narrow. A good proportion and the one followed in the beams shown and described is that their width shall not exceed $4\frac{1}{2}$ inches by more than one-sixth of their depth.

The beams of our series included in the 12, 14, 16 and 18 inch groups while not limited thereto are well adapted for use as joists. These beams do not exceed $4\frac{1}{2}$ inches by more than one-sixth of their depths. The different beams of this range of the series bear a definite relation to one another. For example, the product of depth by the weight per linear foot of any section of the series is substantially (that is within 5 percent) a geometrical mean between the respective products of the depths by weights per linear foot of the section next shallower and the section next deeper. To illustrate—

Depth × weight of the 12 inch beam= $12\times28=336$.

Depth × weight of the 14 inch beam= $14\times33=462$.

Depth × weight of the 16 inch beam= $16\times40=640$.

Depth × weight of the 18 inch beam= $18\times48=864$.

Comparing the 14 inch beam with the next shallower (that is the 12 inch) and the next deeper (that is the 16 inch) to prove 462 is a geometrical mean between 336 and 640, the geometrical mean equals

$$\sqrt{215040}$$

or in round numbers 464 which is well within 5 percent of the product of the depth of the 14 inch beam by its weight per linear foot.

While we have described with great particularity of detail the sizes, shapes and weights of certain sections, it is not to be construed that we are limited thereto as various modifications may be made by those skilled in the art without departing from the invention as defined in the appended claims.

What we claim is:—

1. A series of rolled sections whose depths, weights per unit of length and strengths in the direction of their depths progress by a constant geometrical ratio.

2. A series of rolled sections comprising a plurality of groups of sections, the lightest weight section of each group being deeper and heavier than the lightest weight section in the preceding group, the weights per unit of length and depths of said lightest weight sections progressing by a determined geometrical ratio.

3. A series of solid rolled metal structural I-sections whose depths progress in substantially a constant geometrical ratio and whose weights per linear foot progress in substantially a constant geometrical ratio.

4. A series of solid rolled steel I-beam sections whose depths are multiples of one inch and progress from 12 to 24 inches by five steps, each intermediate depth being substantially or approximately 1.15 times the depth next below and whose respective weights per linear foot are multiples of one pound and progress from 28 to 70 pounds by five steps, each intermediate weight being substantially or approximately 1.20 times the weight of the section next below.

5. A group of solid rolled steel I-beam sections whose minimum weight section is one of the series covered by claim 4 and the width of whose minimum weight section does not exceed four and one-half inches by more than one-sixth of its depth, and whose heavier sections have depths and widths increasing from those of the minimum weight section by increments that have a constant ratio of not less than 3 to 1.

6. A series of solid rolled steel I-beam sections whose depths are not less than 12 nor more than 18 inches and are multiples of one inch, any section in which has a width that exceeds $3\frac{1}{2}$ inches but does not exceed $4\frac{1}{2}$ inches by more than one-sixth of its depth and the product of the depth by the weight per linear foot of any section in which is substantially a geometrical mean between the respective products of the depth by the weight per linear foot of the section next shallower and of the section next deeper.

7. A series of solid rolled steel beam sections whose depths come within predetermined limits measured in multiples of one inch, the width of said sections not exceeding $4\frac{1}{2}$ inches by more than one-sixth of their depths and the product of the depth by the weight per linear foot of any section of the series being substantially or approximately a geometrical mean between the respective products of depths by the weights per linear foot of the section next shallower and of the section next deeper.

In witness whereof, we have hereunto signed our names.

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ROBERT A. MARBLE.