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ABOUT COMPUTER PROGRAMS FOR SIMPLIFIED METHODOLOGY OF COMPLEX ASSESSMENT OF STRENGTH OF TWO-BEAM BEAMS

Abstract. Computer programs for calculation the strength of statically determinable double-support and cantilevered I-beams are based on the previously proposed concept of using safe factor spaces of I-beams and significantly simplify and speed up the calculation process. The programs are created in the Mathcad system and illustrated by a numerous of examples. Programs use unified beam schemes, which geometric and power parameters are set by the user. All further calculation is performed by computer in automatic mode. The computer determines the beam support reactions, builds its specific calculation scheme, depicts the diagrams of the shear forces and bending moments, determines the minimum of I-beam size that satisfies the strength conditions for normal, tangential and equivalent stresses. The completed software developments can be recommended to the students and engineers to use for educational purposes and engineering practice. It is recommended to add more functionality to the programs - to determine the deformations of beams - deflections and angles of rotation of sections, which will significantly expand the range of the considered tasks.

Keywords: *I-beam, strength calculations, simplified methodology, end-to-end computer programs, calculation examples.*

Introduction and statement of the problem. In the era of rapid technology growth, it becomes necessary high education institutions training of specialists with the solid basis of theoretical knowledge and practical skills to create more sophisticated new technology models. Important role plays improvement of the basic disciplines of engineering training aiming to add new knowledge that expands existing theoretical ideas.

One of the significant topic in the strengths of materials course that underpin engineering calculations is the question about the durability of the uni-planar bending structural elements of the bar-shaped structural elements (called beams) in the engineering, construction, and other industries operated in flat bending conditions.

Beams could be in various forms of cross sections, but the most widespread among them are beams of an I-bar profile (Fig. 1), because they combine economic advantages along with easy installation and operation.
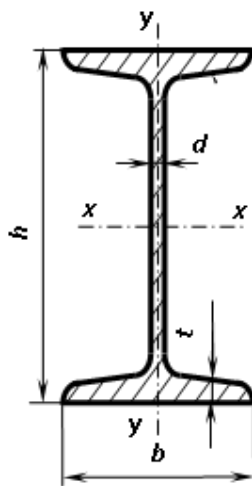

Fig. 1. I-beam (GOST 8239-89)

It is generally accepted [1-5, etc.] that in order to ensure reliable operation, beams must comply with the conditions of its strength at normal (1), tangent (2) and equivalent (3) stresses (normal, shearing and equivalent stress):

$$\sigma_{max} \leq [\sigma]; \tag{1}$$

$$\tau_{max} \leq [\tau]; \tag{2}$$

$$\sigma^{eq}_{max} \leq [\sigma],\qquad\qquad (3)$$

where $[\sigma]$ and $[\tau]$ are the permissible normal and tangent stresses respectively.

In traditional ("manual") calculations, full beam strength testing under conditions (1)-(3) is rather complicated and inefficient because it involves performing a number of graphical constructs and calculations that require appropriate skills and considerable time [6, 7]. As for the large amount of computer-aided computing tools available on the Internet (Abaqus FEA, ANSYS, COSMOSWorks, etc.), which are usually too expensive and complex enough to use, that makes those tools are practically unavailable for the most customers.

In the previously published papers [8, 9] on the basis of thorough theoretical studies, was proposed a simplified (graphical) technique for complex evaluation of the strength of I-beams, based on the so-called safe factor spaces of I-beams (fig. 2).
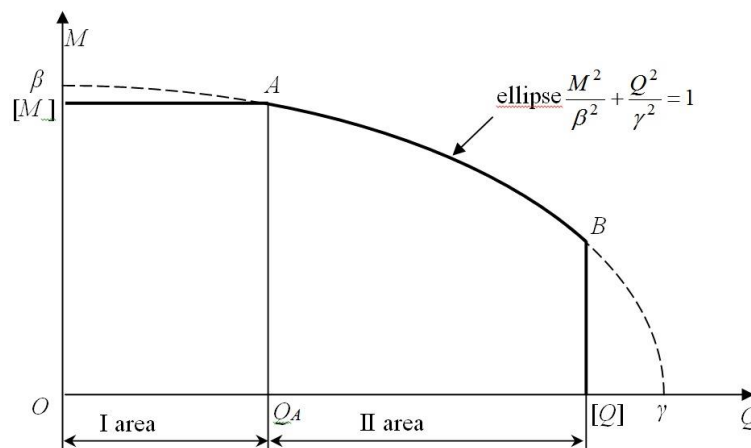

Fig. 2. Plot of the I-beam safe factor space.

Parameters of this space are β, γ, $[M]$, $[Q]$ that depend on the size (number) of the I-bar, its material and the accepted strength theory [8, 9].

Full strength of the beam in the new technique is ensured if all points with the coordinates Q (shear force) and M (bending moment) in the cross sections of the beam are located within the specified factor space. Thus, to provide the full strength test of a particular beam by this method, it is sufficient to have the created diagrams of Q and M and to draw its safe factor space.

This method is used in two modes: dialog and automatic.

In dialog mode, the calculator builds diagrams of Q and M "manually" or using the appropriate computer programs, if any. Then the calculator enters the data from the Q and M diagrams in the cross sections of the beam into the computer and runs special program to determine the I-beam number that satisfies the conditions of strength (1)-(3).

At the automatic mode, the calculator only enters the input data on the dimensions and loads of the beam, and all the necessary calculations and drawings are performed by computer program.

The aim of the work. The purpose of this work is to create end-to-end computer programs to fully calculate the statically determined two support and cantilever beam by statically determined two support and cantilever beam using a simplified (graphical) technique.

Results of the work. Both of these programs are created on the Mathcad platform. They are significantly different from each other only at the input stage.

To set the output data of the **two-beam beams**, they are offered a unified scheme, shown in Figure 3. On this basis, any specific dimensions and loads can be reproduced.

There are two variants of the cantilever beam unified circuits: one for rigid attachment on the right (Fig. 4) and the other for support on the left (Fig. 5).

Positive directions of loads and reactions are supported by plus signs for all unified schemas.

Each type of load can be repeated several times (i = 1, 2, …). In the working versions of the programs used in the examples below, i = 1, 2.

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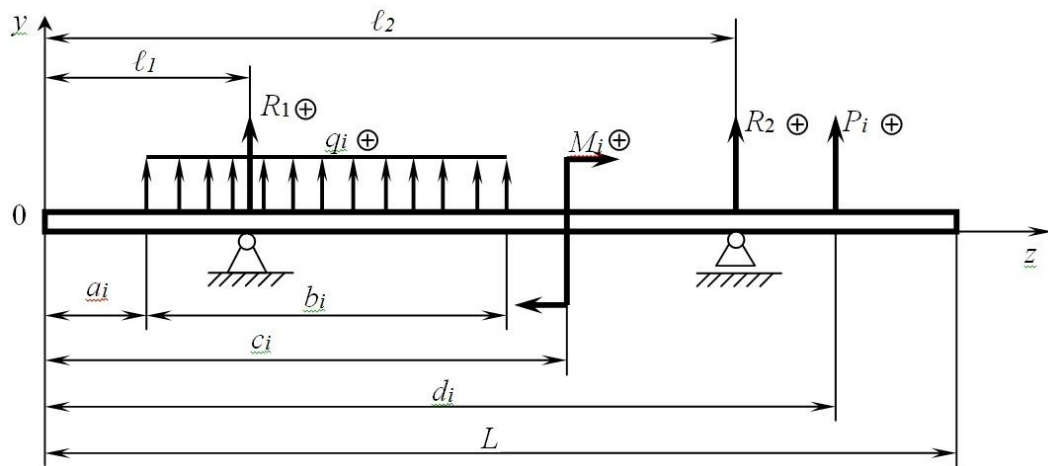
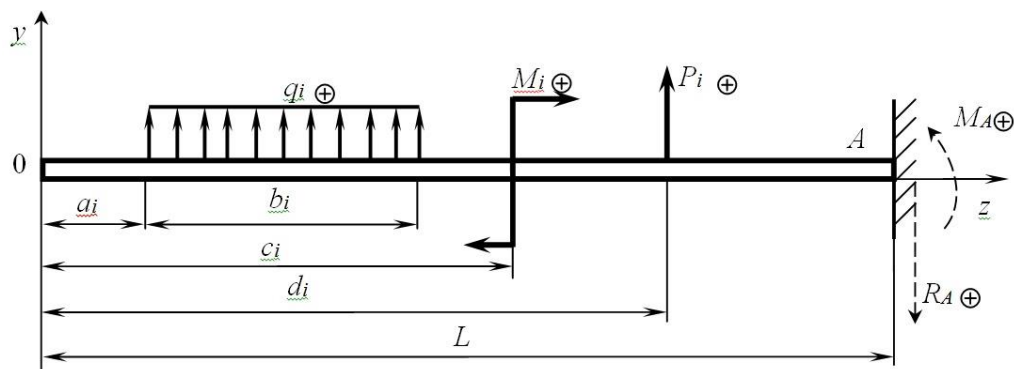Fig. 3. Unified two support beam plot.

Fig. 4. Unified cantilever beam plot with right attachment.
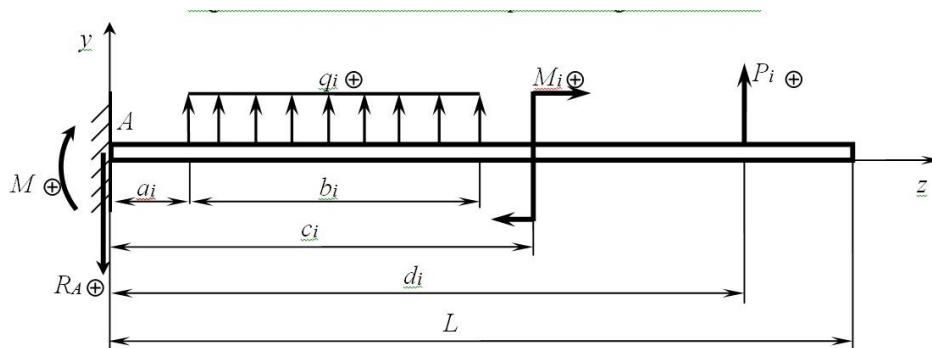

Fig. 5. Unified cantilever beam plot with left attachment.

Both programs determine the support reactions, build the shear force and bending moment diagrams, depict safe factor spaces with the points plotted on them, choose the correct numbers of I-beam sizes, provide evidence that the detected I-number is the smallest one that satisfies all strength conditions.

Program algorithms are based on formulas to calculate the support reactions, the dependences of Q and M values on the coordinate z, the parameters of safe factor spaces for all numbers of I-thaws according to GOST 8239-89 (table 1). These parameters was calculated by using the formulas in [8, 9] for the most common double-Taurus material - steel Art. 3 and the third strength theory, which is more reliable than the fourth because it provides smaller dimensions of safe factor spaces.

Table 1

I-beam safe factor space parameters (steel *Art*.3, $[\sigma] = 160$ *MPa,* third strength theory)

I-beam sizes	β, kN·м	γ, kN	$[M]$, kN·м	$[Q]$, kN
10	7.402	37.758	6.352	30.991
12	10.626	49.714	9.344	39.881

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14	14.643	60.227	13.072	47.911
16	19.346	70.878	17.440	56.051
18	25.201	81.860	22.880	64.658
18a	28.005	80.166	25.440	64.971
20	32.140	93.137	29.440	73.600
20a	35.536	91.513	32.480	74.077
22	40.276	106.648	37.120	84.091
22a	44.154	104.441	40.640	84.285
24	50.100	120.338	46.240	95.097
24a	55.172	118.225	50.720	95.640
27	64.026	147.557	59.360	114.515
27a	70.513	144.836	65.110	115.284
30	81.030	180.046	75.520	137.373
30a	89.361	176.713	82.880	138.548
33	102.367	215.074	95.520	162.549
36	127.657	252.820	118.880	189.787
40	163.097	316.526	152.480	232.241
45	210.216	392.515	196.960	281.236
50	270.712	494.005	254.240	345.828
55	346.380	605.383	325.600	416.990
60	435.470	727.747	409.600	494.526

We will illustrate the created programms with the following examples.

Example 1. For a given fixed beam (Fig. 6), determine the I-beam size, sufficient to ensure its full strength.
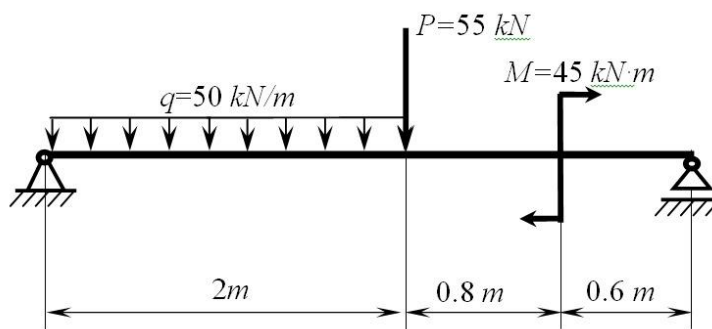

Fig. 6. The beam plot to example 1

Solution

1. Input of concentrated forces, moments of couples and their location:

Enter the concentrated forces P, its position d, moments of couples M and its positions c

$$P := \begin{pmatrix} -55 \\ 0 \end{pmatrix} kN \qquad d := \begin{pmatrix} 2 \\ 0 \end{pmatrix} m \qquad M := \begin{pmatrix} 45 \\ 0 \end{pmatrix} kN \cdot m \qquad c := \begin{pmatrix} 2.8 \\ 0 \end{pmatrix} m$$

2. Input of the length of beam, the support positions, the distributed loads, its positions and lengths:

Enter the distributed loads q, its positions a, its length b, the length of the beam L and the support positions on the beam l_1 та l_2

$$q := \begin{pmatrix} -50 \\ 0 \end{pmatrix} \frac{kN}{m} \qquad a := \begin{pmatrix} 0 \\ 0 \end{pmatrix} m \qquad b := \begin{pmatrix} 2 \\ 0 \end{pmatrix} m \qquad L := 3.4m \qquad l_1 := 0m \qquad l_2 := 3.4m$$

3. Determination of the support reaction forces of the beam:

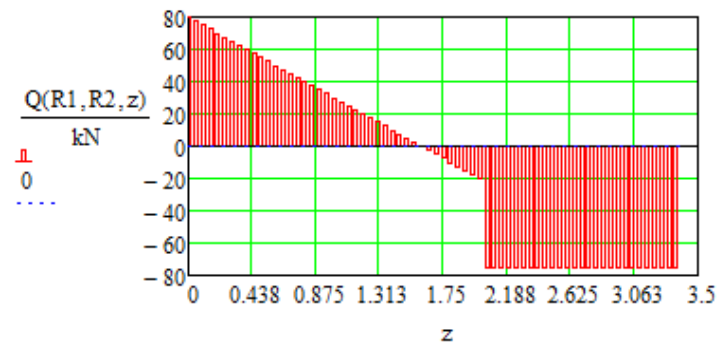$$R2 := \frac{1}{(l_2 - l_1)} \cdot \left[\sum_{i=1}^{\text{rows}(M)} M_i - \sum_{i=1}^{\text{rows}(P)} \left[P_i \cdot (d_i - l_1) \right] - \sum_{i=1}^{\text{rows}(q)} \left[q_i \cdot b_i \cdot \left(a_i + \frac{b_i}{2} - l_1 \right) \right] \right]$$
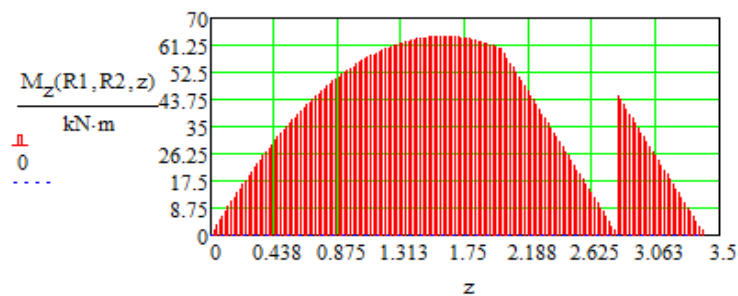
$$R2 = 7.5 \times 10^4 \, \text{N}$$

$$R1 := \frac{1}{(l_2 - l_1)} \cdot \left[- \sum_{i=1}^{\text{rows}(M)} M_i + \sum_{i=1}^{\text{rows}(P)} \left[P_i \cdot (d_i - l_2) \right] - \sum_{i=1}^{\text{rows}(q)} \left[q_i \cdot b_i \cdot \left(l_2 - a_i - \frac{b_i}{2} \right) \right] \right]$$

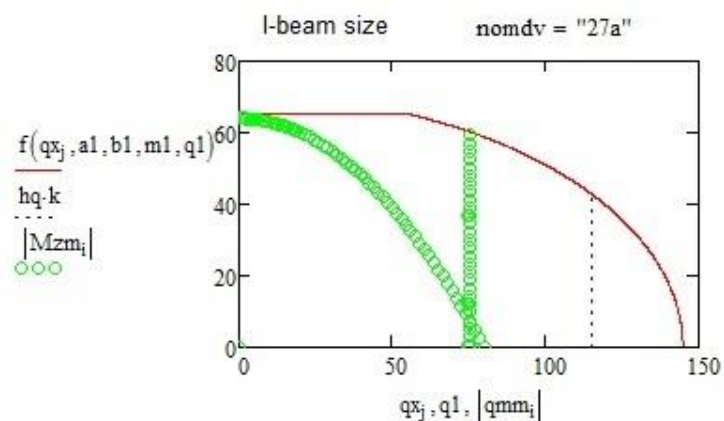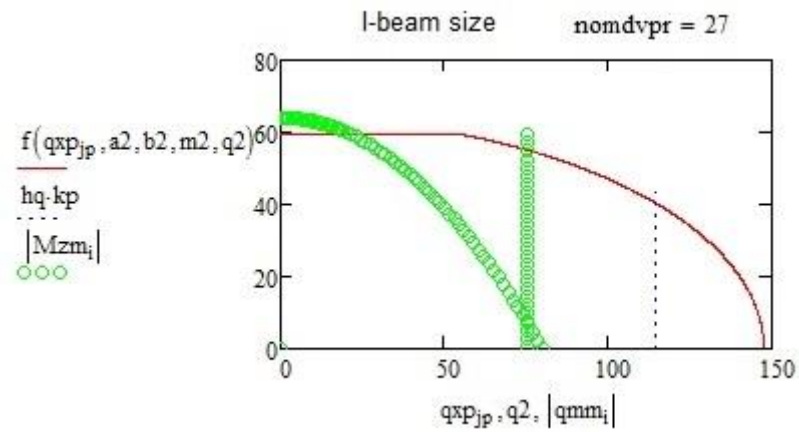$$R1 = 8 \times 10^4 \, \text{N}$$

4. Plot of the shear force diagram:

5. Plot of the bending moment diagram:

6. Determination of the I-beam size:

7. Comparision with the previous I-beam size:

Example 2. For the beam shown in Fig. 7, determine the required I-beam size to ensure its full strength
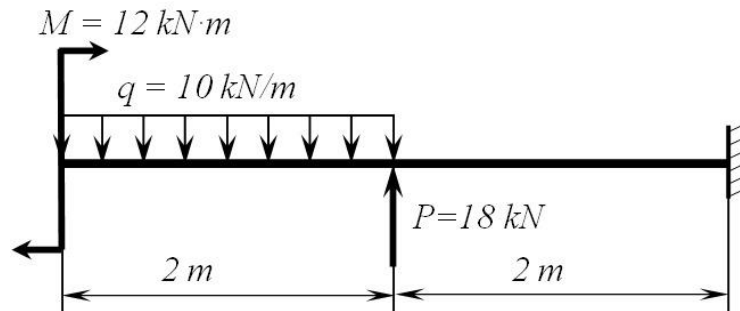

Fig. 7. The beam plot to the example 2

Solution

1. Input of concentrated forces, moments of couples and its positions:

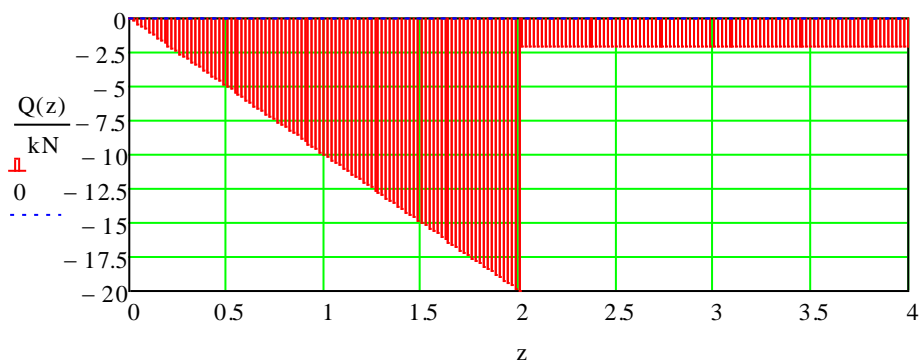Enter the concentrated forces P, its positions d, moments of couple M and its position c

$$P := \begin{pmatrix} 18 \\ 0 \end{pmatrix} kN \qquad d := \begin{pmatrix} 2 \\ 0 \end{pmatrix} m \qquad M := \begin{pmatrix} 12 \\ 0 \end{pmatrix} kN \cdot m \qquad c := \begin{pmatrix} 0 \\ 0 \end{pmatrix} m$$

2. Input of the length of beam, the distributed loads, its positions and lengths and the position of the beam attachment:
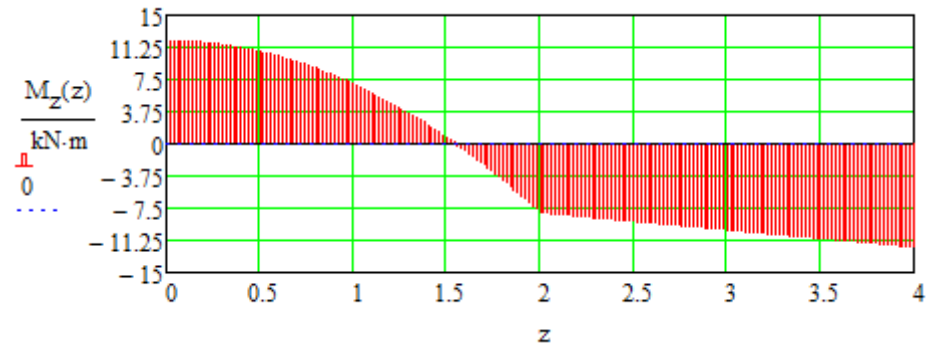
Enter the distributed loads q, its positions a, its lengths b, the beam length L the attachment position lz

$$q := \begin{pmatrix} -10 \\ 0 \end{pmatrix} \frac{kN}{m} \qquad a := \begin{pmatrix} 0 \\ 0 \end{pmatrix} m \qquad b := \begin{pmatrix} 2 \\ 0 \end{pmatrix} m \qquad L := 4m \qquad lz := L$$
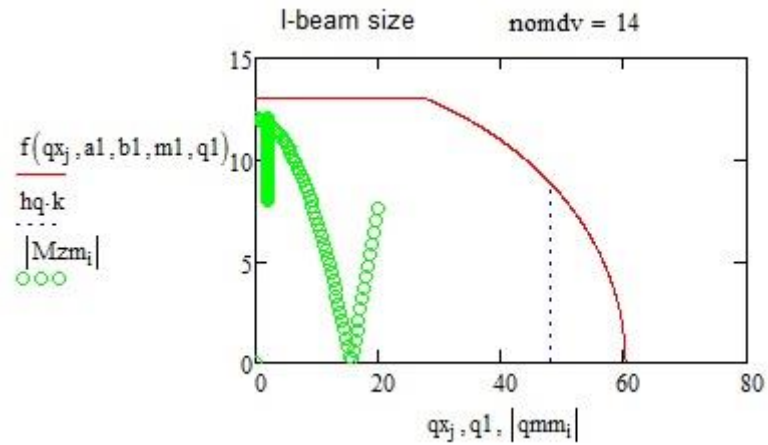
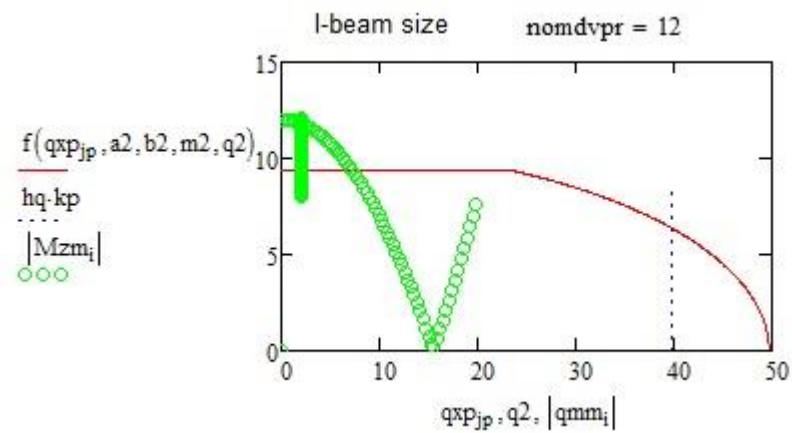3. Plot of the shear force diagram:

4. Plot of the bending moment diagram:

5. Ddetermination of the I-beam size:

6. Comparision with the previous I-beam size:

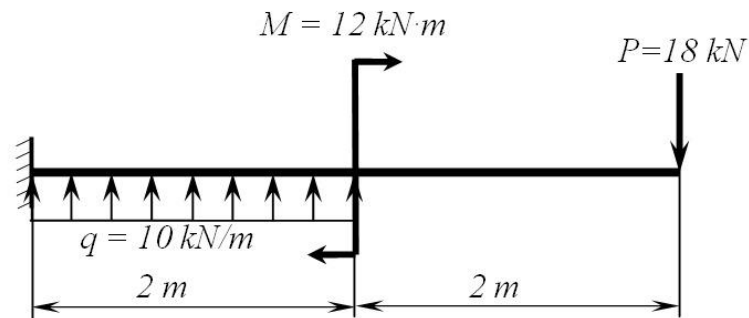**Example 3.** The beam plot for calculation is shown in Fig.8. Determine I-beam size to ensure its full strength.

Fig. 8. The beam plot to example 3

Solution

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1. Input of concentrated forces, moments of couples and its positions:

Enter the concentrated forces P, its positions d, moments of couple M and its position c

$$P := \begin{pmatrix} -18 \\ 0 \end{pmatrix} kN \qquad d := \begin{pmatrix} 4 \\ 0 \end{pmatrix} m \qquad M := \begin{pmatrix} 12 \\ 0 \end{pmatrix} kN \cdot m \qquad c := \begin{pmatrix} 2 \\ 0 \end{pmatrix} m$$

2. Input of the length of beam, the distributed loads, its positions and lengths and the position of the beam attachment:

Enter the distributed loads q, its positions a, its lengths b, the beam length L the attachment position lz
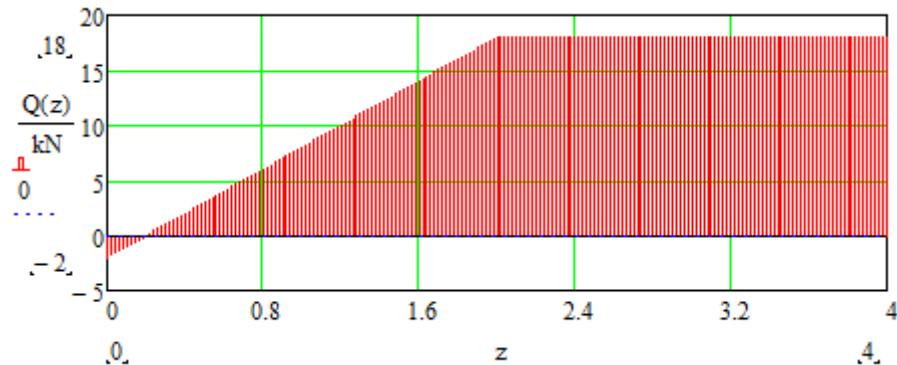
$$q := \begin{pmatrix} 10 \\ 0 \end{pmatrix} \frac{kN}{m} \qquad a := \begin{pmatrix} 0 \\ 0 \end{pmatrix} m \qquad b := \begin{pmatrix} 2 \\ 0 \end{pmatrix} m \qquad L := 4m \qquad lz := 0$$

3. Determination of support reaction force and moment:

$$R_A := \sum_{i=1}^{rows(q)} \left(q_i \cdot b_i \right) + \sum_{i=1}^{rows(P)} \left(P_i \right) \qquad R_A = 2 \times 10^3 \, N$$

$$M_A := \sum_{i=1}^{rows(q)} \left[q_i \cdot b_i \cdot \left(a_i + \frac{b_i}{2} \right) \right] + \sum_{i=1}^{rows(P)} \left(P_i \cdot d_i \right) - \sum_{i=1}^{rows(M)} \left(M_i \right) \qquad M_A = -6.4 \times 10^4 \, J$$

4. Plot of the shear force diagram:

5. Побудова епюри згинальних моментів:
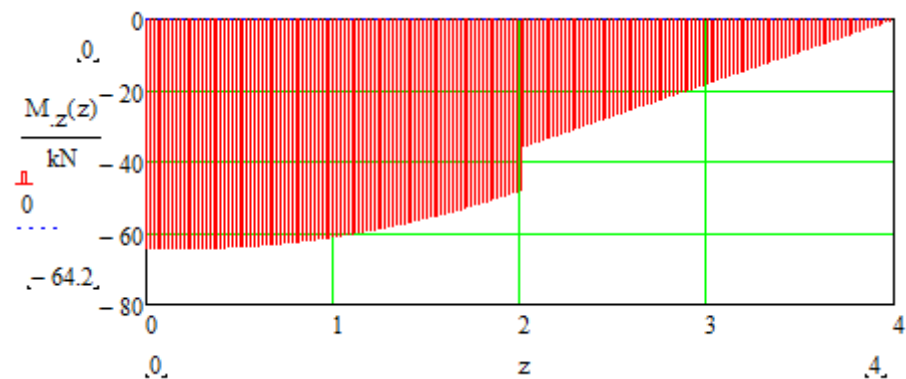
6. Ddetermination of the I-beam size:

6. Comparision with the previous I-beam size:

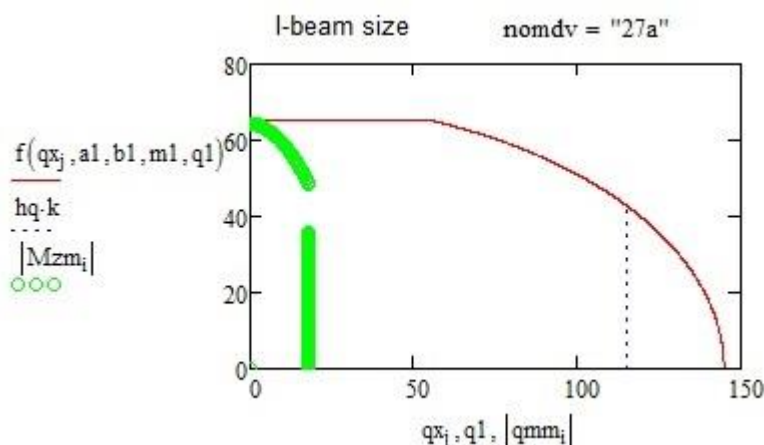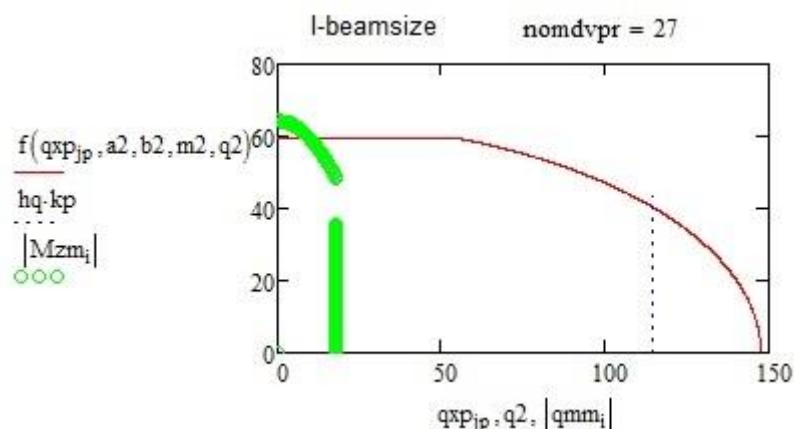

Conclusions. Computer programs are created in Mathcad and illustrated with a number of examples to calculate the strength of statically defined two-point and cantilever beams. These programs are based on the previously proposed concept of using secure quotient spaces of double-Taurus, which significantly simplifies and speeds up the computation process.

The completed developments can be recommended to the students and engineers to use for educational purposes and engineering practice.

The algorithm to define deformations of beams - bends and angles of cross section, which will allow to expand significantly the range of solved problems is also should be added to the created programs.

References

1. Pisarenko G.S. Strength of materials:.of High.Educ./ G.S.Pisarenko,O.L. Kvitka,E.S.Umanskiy.- K.:High Scool.,2004.-655p.

2. Kalinovskaya, T.G. Strength materials: Tutorial / T.G.Kalinovskaya Handbook for Inst, N.A.Drozdova, A.T.Ryabova –Naydan – Krasnoyarsk: Siberia Federal University, 2016 – 164p.

3. Chakarbarti M. Strength Of Materials / M. Chakarbarti. – S. K. Kataria & Sons, 2009. – 1000 p. ISBN 8185749302, 9788185749303

4. Bansal R. K. A Textbook of Strength of Materials / R. K. Bansal. – Laxmi Publications, 2010. – 1106 p. ISBN 8131808149, 9788131808146

5. Purushothama Rai. P. Strength of Materials / P.Rai. Purushothama, V.Ramasamy.–Pearson India, 2012. – 1039 p. ISBN 8131798895, 9788131798898.

6. Кутовий Л. В. Збірник розрахунково – графічних завдань з курсу "Опір матеріалів" (для студентів всіх механічних спеціальностей денної форми навчання) / Л. В. Кутовий [та ін.]. – Краматорськ: ДДМА, 2007. – 220 с.

7. Каюмов Р.А. Расчёт балки на прочность и жёсткость при прямом поперечном изгибе: Методические указания для выполнения расчётно – графического задания / Р.А. Каюмов, И.З. Мухамедова, Д.Е. Страхов. – Казань: КГАСУ, 2009. – 24 с.

8. Холодняк Ю.С. Совершенствование методики прочностного расчёта двутавровой балки и её изложения в курсах технических дисциплин / Ю.С. Холодняк, А.В. Периг, И.А. Матвеев //

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9. Холодняк Ю. С. Развитие методологии прочностных расчетов двутавровых балок / Ю. С. Холодняк, А. В. Периг, С. В. Капорович // Научный Вестник ДГМА : Сборник научных трудов. – Краматорск: ДГМА, 2015. – № 2 (17Е). – С. 103 –114.

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Донбаська державна машинобудівна академія

ПРО КОМП'ЮТЕРНІ ПРОГРАМИ ДО СПРОЩЕНОЇ МЕТОДИКИ КОМПЛЕКСНОЇ ОЦІНКИ МІЦНОСТІ ДВОТАВРОВИХ БАЛОК

Створено в системі Mathcad і проілюстровано рядом прикладів наскрізні комп'ютерні програми розрахунків на міцність статично визначуваних двохопорних і консольних двотаврових балок, які базуються на раніше запропонованій концепції використання безпечних факторних просторів двотаврів і суттєво спрощують і прискорюють процес обчислень. Програми використовують уніфіковані схеми балок, геометричні й силові параметри яких задає користувач. Увесь подальший розрахунок виконується комп'ютером в автоматичному режимі. Комп'ютер визначає опорні реакції балки, будує її конкретну розрахункову схему, також епюри поперечних сил і згинальних моментів, визначає мінімальний номер двотавра, який задовольняє умови міцності за нормальними, дотичними і еквівалентними напруженнями. У подальшому планується створення аналогічних програм для балок із швелерів. Виконані розробки можуть бути рекомендовані студентам та виробничим фахівцям для використання в навчальних цілях й інженерній практиці. Створені програми доцільно доповнити можливостями визначення деформацій балок – прогинів і кутів повороту перерізів, що дозволить суттєво розширити коло розв'язуваних задач.

Ключові слова: *двотаврові балки, розрахунки на міцність, спрощена методика, наскрізні комп'ютерні програми, приклади розрахунків.*

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Донбасская государственная машиностроительная академия

РАЗРАБОТКА КОМПЬЮТЕРНЫХ ПРОГРАММ ДЛЯ УПРОЩЁННОЙ МЕТОДИКИ РАСЧЁТА НА ПРОЧНОСТЬ ДВУТАВРОВЫХ БАЛОК

Созданы в системе Mathcad и проиллюстрированы рядом примеров сквозные компьютерные программы расчётов на прочность статически определимых двухопорных и консольных двутавровых балок, которые базируются на ранее предложенной концепции использования безопасных факторных пространств двутавров и существенно упрощают и ускоряют процесс вычислений. Программы используют унифицированные схемы балок, геометрические и силовые параметры которых задает пользователь. Весь дальнейший расчёт выполняется компьютером в автоматическом режиме. Компьютер определяет опорные реакции балки, строит её конкретную расчётную схему, изображает эпюры поперечных сил и изгибающих моментов, устанавливает минимальный номер двутавра, удовлетворяющий условия прочности по нормальным, касательным и эквивалентным напряжениям. Выполненные разработки могут быть рекомендованы студентам и производственным специалистам для использования в учебных целях и инженерной практике. Созданные программы целесообразно дополнить возможностями определения деформаций балок – прогибов и углов поворота сечений, что позволит существенно расширить круг решаемых задач.

Ключевые слова: *двутавровые балки, расчёты на прочность, упрощённая методика, сквозные компьютерные программы, примеры расчетов.*