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BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED AND CLAMPED FLAT, RECTANGULAR SANDWICH PANELS UNDER EDGEWISE COMPRESSION

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BUCKLING COEFFICIENTS FOR SIMPLY SUPPORTED AND CLAMPED FLAT, RECTANGULAR SANDWICH PANELS UNDER EDGEWISE COMPRESSION[1]

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Abstract

This report presents curves of coefficients and formulas for use in calculating the buckling of flat panels of sandwich construction under edgewise compressive loads. The curves were derived for sandwich panels having one facing of either of two orthotropic materials, the other facing of an isotropic material; both facings of orthotropic material; both facings of isotropic material; and cores of orthotropic or isotropic material. Parameters are chosen so that facings may be of different thicknesses and so that isotropic facings can also be of different isotropic materials.

Curves were derived for various edge conditions, simply supported and clamped.

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[1]This note is another progress report in the series (Military Handbook 23 Working Group, Item 58-2) prepared and distributed by the Forest Products Laboratory under U.S. Navy, Bureau of Naval Weapons Order No. 19-64-8041 (WEPS) and U.S. Air Force Contract 33(657)63-358. Results here reported are preliminary and may be revised as additional data become available.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Introduction

The derivation of formulas for the buckling loads of rectangular sandwich panels subjected to edgewise compression is given in Forest Products Laboratory Report No. 1583-B.[3] These formulas are derived for panels having dissimilar facings and orthotropic cores, the most general type of sandwich panel; and for several combinations of simply supported and clamped edges. The cores are assumed to be of such a nature that the stresses in them associated with strains in the plane of the panel may be neglected in comparison with the similar stresses in the facings and that the elastic modulus normal to the facings is so great that the related strain may be neglected.

For honeycomb cores with hexagonal cells (a particular type of orthotropic core) it was found that the modulus of rigidity associated with the directions perpendicular to the ribbons of which honeycomb is made and the length of the cells is roughly 40 percent of the modulus of rigidity associated with the directions parallel to those ribbons and the length of the cells. Making use of this fact, design curves for sandwich panels with simply supported and clamped edges and having isotropic facings and such honeycomb cores were published in Forest Products Laboratory Report No. 1854.[4]

For the glass-fabric laminates currently used for facings, it was found that the numerical values of parameters involving the elastic properties of orthotropic facings that enter the formula for the buckling coefficient could be divided into three groups so that in each group the values do not vary greatly from one laminate to another. Using this fact, design curves for simply supported sandwich panels having similar orthotropic (glass-fabric laminate) facings were published in Forest Products Laboratory Report No. 1867.[5]

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[3] Ericksen, W. S., and March, H. W. Effects of shear deformation in the core of a flat rectangular sandwich panel - Compressive buckling of sandwich panels having dissimilar facings of unequal thickness. Forest Products Lab. Rpt. 1583-B. 48 pp., illus. Revised 1958.

[4] Norris, C. B. Compressive buckling curves for flat sandwich panels with isotropic facings and isotropic or orthotropic cores. Forest Products Lab. Rpt. 1854. 22 pp., illus. Revised 1958.

[5] Norris, Charles B. Compressive buckling curves for simply supported sandwich panels with glass-fabric-laminate facings and honeycomb cores. Forest Products Lab. Rpt. 1867. 18 pp., illus. 1958.

Compressive buckling curves were also calculated for simply supported sandwich panels with honeycomb and isotropic cores and with one facing consisting of an orthotropic material (glass-fabric laminate) and the other facing of an isotropic material, and were presented in Forest Products Laboratory Report No. 1875.[6]

This report also presents compressive buckling curves for sandwich panels with dissimilar, as well as similar, facings. The combinations of elastic properties of the orthotropic (glass-fabric laminate) facings may fall into any of the three principal groups. Curves are presented for four different combinations of panel edge support (simply supported or clamped).

Facing Elastic Properties

The various elastic properties of the facings can be combined into three convenient parameters for presentation of curves of buckling coefficients. These parameters are defined by the following:

$$\left.\begin{aligned} \alpha_i &= \sqrt{\frac{E_{bi}}{E_{ai}}} \\ \beta_i &= \alpha_i \mu_{abi} + 2\gamma_i \\ \gamma_i &= \frac{\lambda_i G_{bai}}{\sqrt{E_{ai} E_{bi}}} \end{aligned}\right\} \qquad (1)$$

where $\lambda_i = 1 - \mu_{abi}\mu_{bai}$; E_{ai} and E_{bi} are the moduli of elasticity of a facing in the a and b directions, respectively (see fig. 1); G_{abi} is the facing shear modulus associated with shear distortion in the plane of the facing (a-b plane); μ_{abi} is facing Poisson's ratio of contraction in the a direction to extension in the b direction due to a tensile stress in the b direction; μ_{bai} is facing Poisson's ratio

[6] Norris, Charles B. Compressive buckling curves for flat sandwich panels with dissimilar facings. Forest Products Lab. Rpt. No. 1875. 11 pp., illus. 1960.

of contraction in the b direction to extension in the a direction due to a tensile stress in the a direction; and i = 1,2, denotes facing 1 or facing 2.

For the computation of buckling coefficients presented in this report, facing 1 was taken to be isotropic and having a Poisson's ratio of $\mu_{ba1} = \mu_{ab1} = \mu_1 = 1/4$. For this facing, $E_{a1} = E_{b1} = E_1$ and $G_{ba1} = G_1 = \frac{E_1}{2(1 + \mu_1)}$ and the parameters given by formulas (1) reduce to

$$\alpha_1 = 1; \quad \beta_1 = 1; \quad \lambda_1 = 3/8.$$

Facing 2 was taken to be orthotropic. A wide variety of materials could be selected to give a range of values of parameters α β and λ but values of elastic properties of glass-fabric laminates were chosen. Data presented in Military Handbook-17[7] and combined to reasonable average values in Forest Products Laboratory Report No. 1867[5] showed that elastic properties of polyester and epoxy laminates of glass fabrics 112, 116, 120, 128, 143, 162, 164, 181, 182, 183, and 184 could be grouped to give parameter values of

$$\beta_2 = 0.6 \quad \text{and} \quad \lambda_2 = 0.2.$$

The value of α_2 for all laminates listed except that with 143 fabric was considered to be 1.0; and the 143 fabric laminate had $\alpha_2 = 3/2$ or $\alpha_2 = 2/3$, depending upon orientation.

Although the values of these parameters originated in evaluation of glass-fabric laminates, they would apply to other orthotropic materials. Thus $\alpha_2 = 1$, $\beta_2 = 0.6$, and $\lambda_2 = 0.2$ would apply to any orthotropic material having $E_a = E_b = E$, $\mu_{ab} = 0.2$, $\mu_{ba} = 0.2$,[8] and $G_{ba} = 0.21E$. Similarly, for $\alpha_2 = 3/2$, $\beta_2 = 0.6$, and $\lambda_2 = 0.2$, the material would have $E_a = \frac{4}{9} E_b$, $\mu_{ab} = 0.13$, $\mu_{ba} = 0.30$,[8] and $G_{ba} = 0.21\sqrt{E_a E_b}$; and for $\alpha_2 = 2/3$, $\beta_2 = 0.6$, and $\lambda_2 = 0.2$ the material would have $E_a = \frac{9}{4} E_b$, $\mu_{ab} = 0.30$, $\mu_{ba} = 0.13$,[8] and $G_{ba} = 0.21\sqrt{E_a E_b}$.

[7] U.S. Department of Defense. Plastics for flight vehicles - Part I, Reinforced plastics. Military Handbook 17. 1959.

[8] Assuming the relationship $E_a \mu_{ba} = E_b \mu_{ab}$.

Formulas

Load is applied to two opposite edges of the panel, as shown in figure 1. The length of these edges is b and the length of the other two edges is a. The load is applied at the neutral–axis of the panel so that the panel does not bend until the critical load is reached. It follows that the strains in the two facings are equal and the critical stress in each facing is given by

$$F_{c1} = \frac{N}{t_1\left(1 + \frac{A_2}{A_1}\right)} \tag{2}$$

and

$$F_{c2} = \frac{N}{t_2\left(1 + \frac{A_1}{A_2}\right)} \tag{3}$$

where N is the critical load of the sandwich panel in pounds per inch of edge, and t_1 and t_2 are, respectively, the thickness of the isotropic and the orthotropic facings. The parameter A is given by

$$A_i = \frac{t_i}{\lambda_1}\sqrt{E_{ai}E_{bi}} \tag{4}$$

where i = 1,2 denotes facing 1 or facing 2.

The buckling load of the sandwich, per unit panel width, N, is given by the formula [3]

$$N = K_M\frac{\pi^2}{b^2}D + K_1\frac{\pi^2}{b^2}D_1 + K_2\frac{\pi^2}{b^2}D_2 \tag{5}$$

where b is length of the loaded edge of the panel; D is stiffness of spaced facings given by the formula

$$D = \frac{A_1 A_2}{A_1 + A_2} h^2 \tag{6}$$

where h is the distance between facing centroids; D_1 and D_2 are stiffnesses of individual facings given by the formula

$$D_i = \frac{t_i^{\,3} \sqrt{E_{ai} E_{bi}}}{12\lambda_i} \tag{7}$$

where i = 1,2, denotes facing 1 or facing 2; and coefficients K_M K_1 and K_2 may be read from the curves presented; or calculated from the following formulas:

$$K_M = \frac{\psi_1 K_2 + (1 + \frac{R}{c_4}) B_2 V}{\psi_2 + \psi_3 Q_2 V + \frac{R}{c_4} B_2 V^2} \tag{8}$$

$$K_i = \alpha_i c_1 + 2\beta_i c_2 + \frac{c_3}{\alpha_i} \tag{9}$$

where

$$\psi_1 = T + (1 - T)\frac{K_1}{K_2} \cdot \frac{B_2}{B_1} \tag{10}$$

$$\psi_2 = T^2 + 2T(1 - T)\frac{B_{12}}{B_1} + (1 - T)^2 \frac{B_2}{B_1} \tag{11}$$

$$\psi_3 = T + (1 - T)\frac{Q_1}{Q_2} \cdot \frac{B_2}{B_1} \tag{12}$$

$$B_i = c_1 c_3 - \beta_i^{\,2} c_2^{\,2} + \gamma_i c_2 K_i \tag{13}$$

$$B_{12} = \left(\frac{\alpha_1^{\,2} + \alpha_2^{\,2}}{2\alpha_1\alpha_2}\right) c_1c_3 - \beta_1\beta_2 c_2^{\,2} + \frac{c_2}{2}(\gamma_1 K_2 + \gamma_2 K_1) \qquad (14)$$

$$Q_i = \alpha_i c_1 \frac{R}{c_4} + (1 + \frac{R}{c_4})\gamma_i c_2 + \frac{c_3}{\alpha_i} \qquad (15)$$

The parameters of these formulas are given by the following expressions:

$$T = \frac{A_1}{A_1 + A_2} \qquad (16)$$

$$V = \frac{A_1A_2}{A_1 + A_2}\,\frac{\pi^2 t_c}{b^2 G_{ca}} \qquad (17)$$

$$R = \frac{G_{ca}}{G_{cb}} \qquad (18)$$

where G_{cb} and G_{ca} are the moduli of transverse rigidity of the core associated with the directions of the loaded and unloaded edges of the panel, as shown in figure 1, and t_c is the core thickness.

The values of c_1, c_2, c_3, and c_4 depend upon the panel aspect ratio, b/a the integral number of longitudinal half waves, n, into which the panel buckles, and the panel edge conditions. Values of n are chosen to produce minimum values of N.

For a panel with all edges simply supported:

$$c_1 = c_4 = \frac{a^2}{n^2b^2}, \quad c_2 = 1, \quad \text{and} \quad c_3 = \frac{n^2b^2}{a^2}$$

For a panel with loaded edges simply supported and other edges clamped:

$$c_1 = \frac{16a^2}{3n^2b^2}, \quad c_2 = \frac{4}{3}, \quad c_3 = \frac{n^2b^2}{a^2}, \quad \text{and} \quad c_4 = \frac{4a^2}{3n^2b^2}$$

For a panel with loaded edges clamped and other edges simply supported:

$$\text{For } n = 1 \quad c_1 = c_4 = \frac{3a^2}{4b^2}, \quad c_2 = 1, \quad c_3 = 4\frac{b^2}{a^2}$$

$$\text{For } n \geq 2 \quad c_1 = c_4 = \frac{a^2}{(n^2+1)b^2}, \quad c_2 = 1, \quad c_3 = \frac{n^4 + 6n^2 + 1}{n^2 + 1} \cdot \frac{b^2}{a^2}$$

For a panel with all edges clamped:

$$\text{For } n = 1 \quad c_1 = 4c_4 = 4\frac{a^2}{b^2}, \quad c_2 = \frac{4}{3}, \quad c_3 = 4\frac{b^2}{a^2}$$

$$\text{For } n \geq 2 \quad c_1 = 4c_4 = \frac{16a^2}{3(n^2+1)b^2}, \quad c_2 = \frac{4}{3}, \quad c_3 = \frac{n^4 + 6n^2 + 1}{n^2 + 1} \cdot \frac{b^2}{a^2}$$

Discussion of Design Curves

Buckling coefficient curves for sandwich panels are presented in figures 2 to 125. The figures are divided into four main groups, depending on the type of support at the panel edges. Each group contains a set of curves for sandwich having both facings isotropic and three sets of curves for sandwich having dissimilar facings or both facings orthotropic, one set for each value of the parameter α_2 which differentiates between the three types of orthotropic glass-laminate facings.

The figures contain a family of curves consisting of a plot of KM against ab for various values of V. The families in each set of curves differ because they apply to different values of R. Each cusped curve is made up of portions of the curve for the n that gives the least value of K_M The parameter a/b is used in the left half of the curve sheets, and the parameter b/a in the right half. Thus, values of K_M for values of a/b from zero to infinity may be read.

Limits

When a/b is zero, minimum values are given by $K_M = \frac{1}{V}$. For other values of a/b, as the value of V increases, the value of K_M decreases and the minimum points on the curve move to the left. There is a value of V for which the first minimum point of the curve occurs at a/b equal to zero, the K_M intercept. This minimum point is common to the curves associated with all numbers of half waves. Of these curves, the curve for an infinite number of half waves yields the least critical value and is a horizontal straight line. These straight lines are shown on the curve sheets. If V is given a value equal to or greater than that associated with these straight lines, the critical value of K_M is $\frac{1}{V}$. This is the "shear instability limit" of the critical load because substitution into formula (5) results in $N = \frac{h^2}{t_c} G_{ca}$ for sandwich with facings so thin that D_1 and D_2 are negligible. Thus, N is dependent upon core shear modulus, G_{ca} and not upon elastic properties of facings.

Curves are provided for three values of the parameter R (0.4,1.0, and 2.5). Values of K_M for other values of R may be estimated by reading from the curves the K_M values for these three values of R and plotting them against R. The estimate may be made by reading the value of K_M at the required value of R from a smooth curve sketched through the points. It should be noted that the curves for V equal to zero are, of course, independent of R. For convenience, these curves are duplicated in all three figures to which each applies.

The parameter T (formula (16)) was devised as a means of convenience in handling the analysis and presentation of results for sandwich with dissimilar facings. The role of T and its range of values can be understood most easily by examining its place in the parameters of the K_M expression. T appears in the equations for ψ_1, ψ_2, and ψ_3 (equations (10), (11), and (12)). If T = 0 is substituted into these equations, they become

$$\psi_1 = \frac{K_1 B_2}{K_2 B_1}; \quad \psi_2 = \frac{B_2}{B_1}; \quad \psi_3 = \frac{Q_1 B_2}{Q_2 B_1}$$

and substitution of these expressions into formula (8) for K_M result in

$$K_M = \frac{K_1 \frac{B_2}{B_1} + (1 + \frac{R}{c_4}) B_2 V}{\frac{B_2}{B_1} + Q_1 \frac{B_2}{B_1} V + \frac{R}{c_4} B_2 V^2} = \frac{K_1 + (1 + \frac{R}{c_4}) B_1 V}{1 + Q_1 V + \frac{R}{c_4} I_1 V^2} \qquad (19)$$

which is dependent only upon the properties of facing 1 as indicated by the appearance of only 1 as subscripts in the final expression (19). Hence, T = 0 establishes a limit wherein both facings are of type 1 material having the same values of α_1 β_1 and λ_1 but not necessarily having the same elastic moduli or thickness. For the curves presented in this report, type 1 material was defined as being isotropic.

If T = 1 is substituted into equations for ψ_1, ψ_2 and ψ_3 they become

$$\psi_1 = 1, \quad \psi_2 = 1, \quad \psi_3 = 1$$

and the resulting expression for K_M becomes

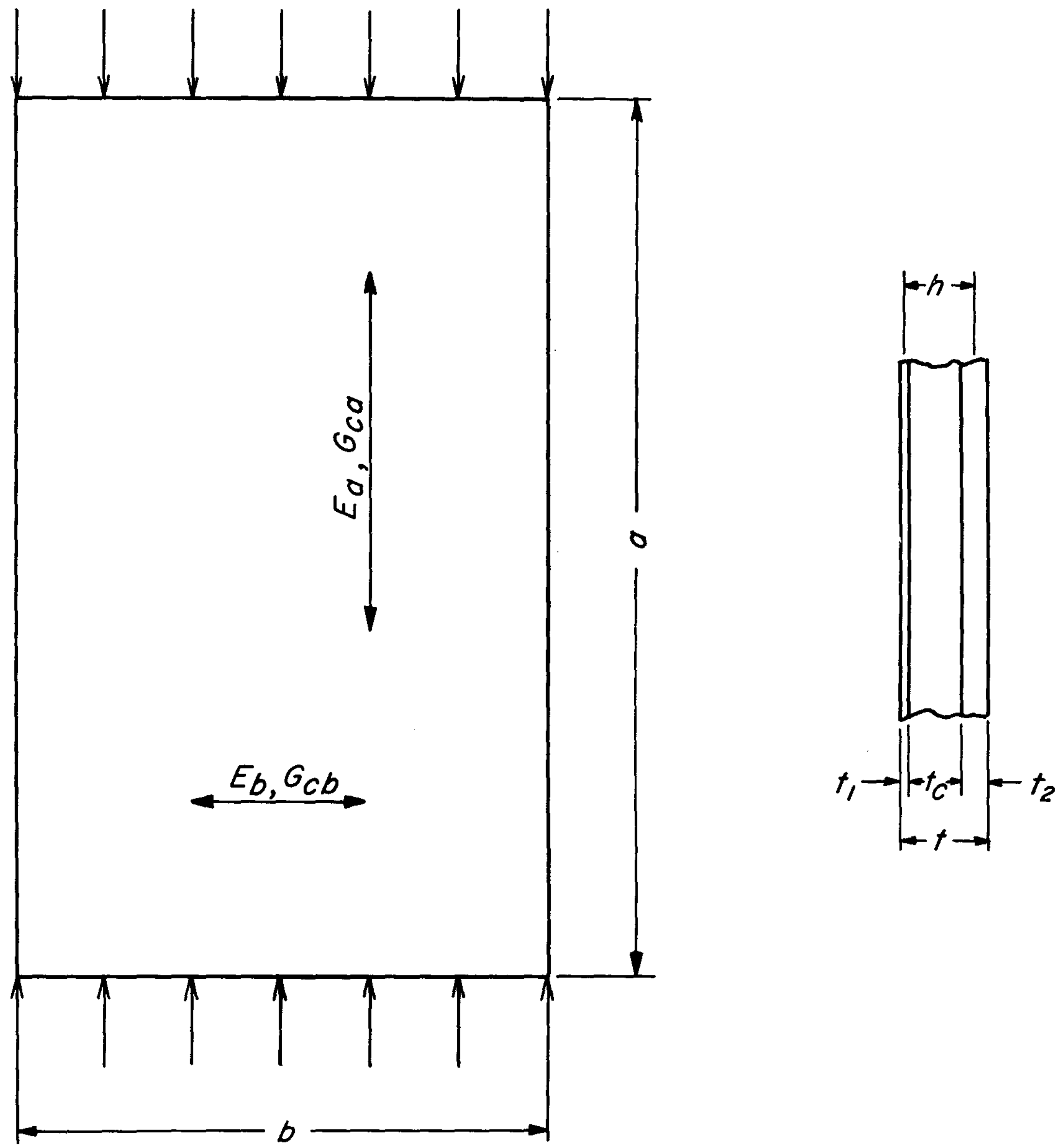
$$K_M = \frac{K_2 + (1 + \frac{R}{c_4}) B_2 V}{1 + Q_2 V + \frac{R}{c_4} B_2 V^2} \qquad (20)$$

which is dependent only upon the properties of facing 2. Hence, T = 1 establishes a limit wherein both facings are of type 2 material having the same values of α_2, β_2, and λ_2 but not necessarily having the same elastic moduli or thickness. For the curves presented in this report, type 2 material was defined as being orthotropic.

The range of values for T lies between 0 and 1 but curves for sandwich having one facing isotropic and the other orthotropic are presented for values of the parameter T of 1/3 and 2/3. Values of K_M for other values of T may be estimated by interpolating linearly between values of K_M given in any two adjacent curves presented (T = 0, 1/3, 2/3, and 1).

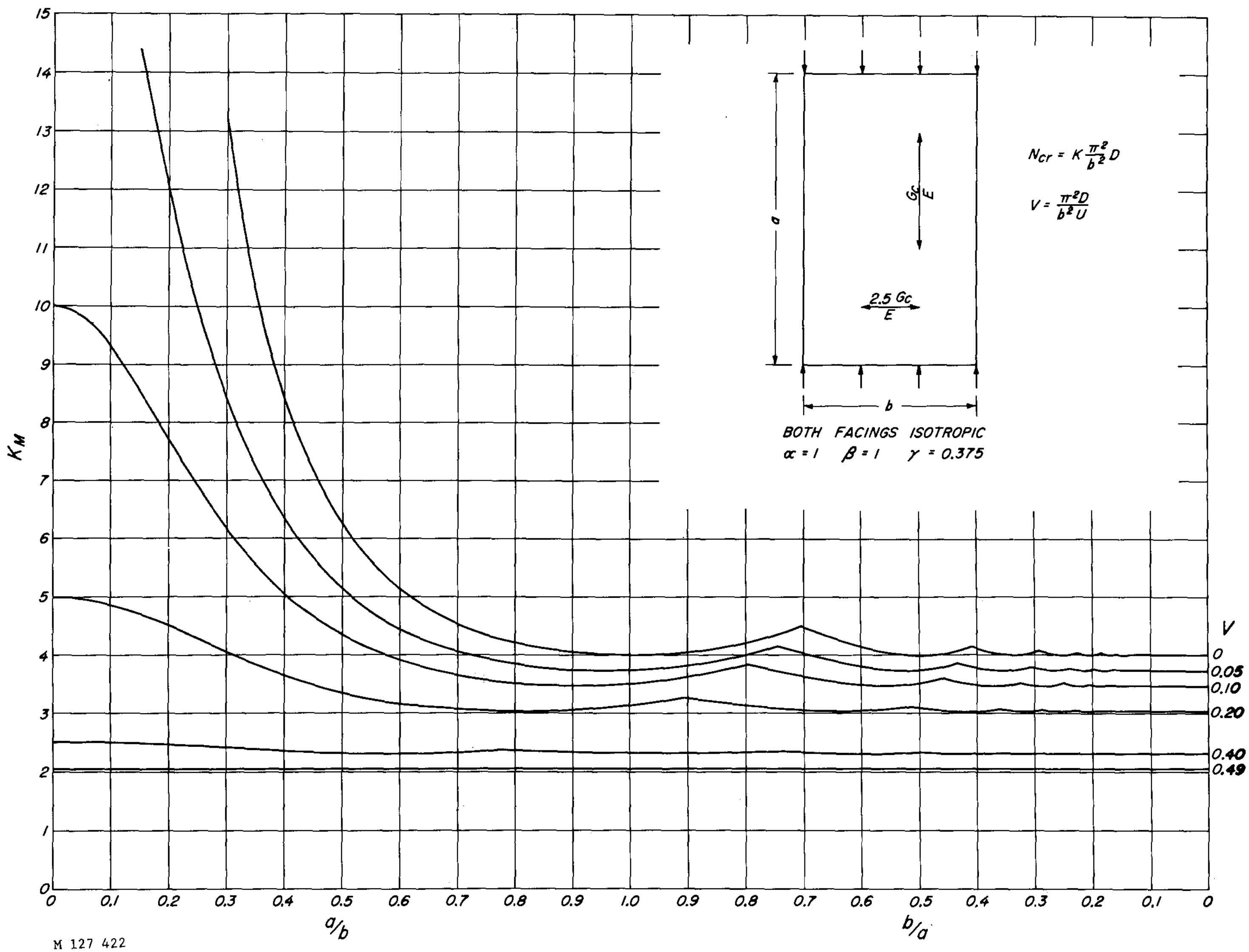
It should not be overlooked that for $T \neq 0$ or $T \neq 1$ the facings of the sandwich are dissimilar. For example, it is not sufficient to place $A_1 = A_2$ in the definition of $\underline{T}$ and suppose that $T = 1/2$ represents sandwich with similar facings because setting $A_1 = A_2$ does not result in $K_1 = K_2$, or $B_1 = B_2$, etc., as is necessary for sandwich with similar facings.

The foregoing has discussed analysis and curves presented for the buckling coefficients because the primary portion of the buckling load $\underline{N}$ is given by the first term of formula (5). The other two terms of formula (5) involving stiff- ness of individual facings, $\underline{D_1}$ and $\underline{D_2}$ have buckling coefficients $\underline{K_1}$ and $\underline{K_2}$. The $\underline{K_1}$ and $\underline{K_2}$ coefficients can be obtained from the $\underline{K_M}$ curves for $T = 0$ and $= 1$, respectively, for $V = 0$. This can be seen by examining formulas (19) and (20) for $V = 0$. The effects of adding individual facing stiffness will usually be small unless the panel is very short. For convenience and greater accuracy in con- sidering buckling of short panels, logarithmic plots of $\underline{K_1}$ and $\underline{K_2}$ as functions of $\underline{a/b}$ are given in figures 32, 63, 94, and 125.



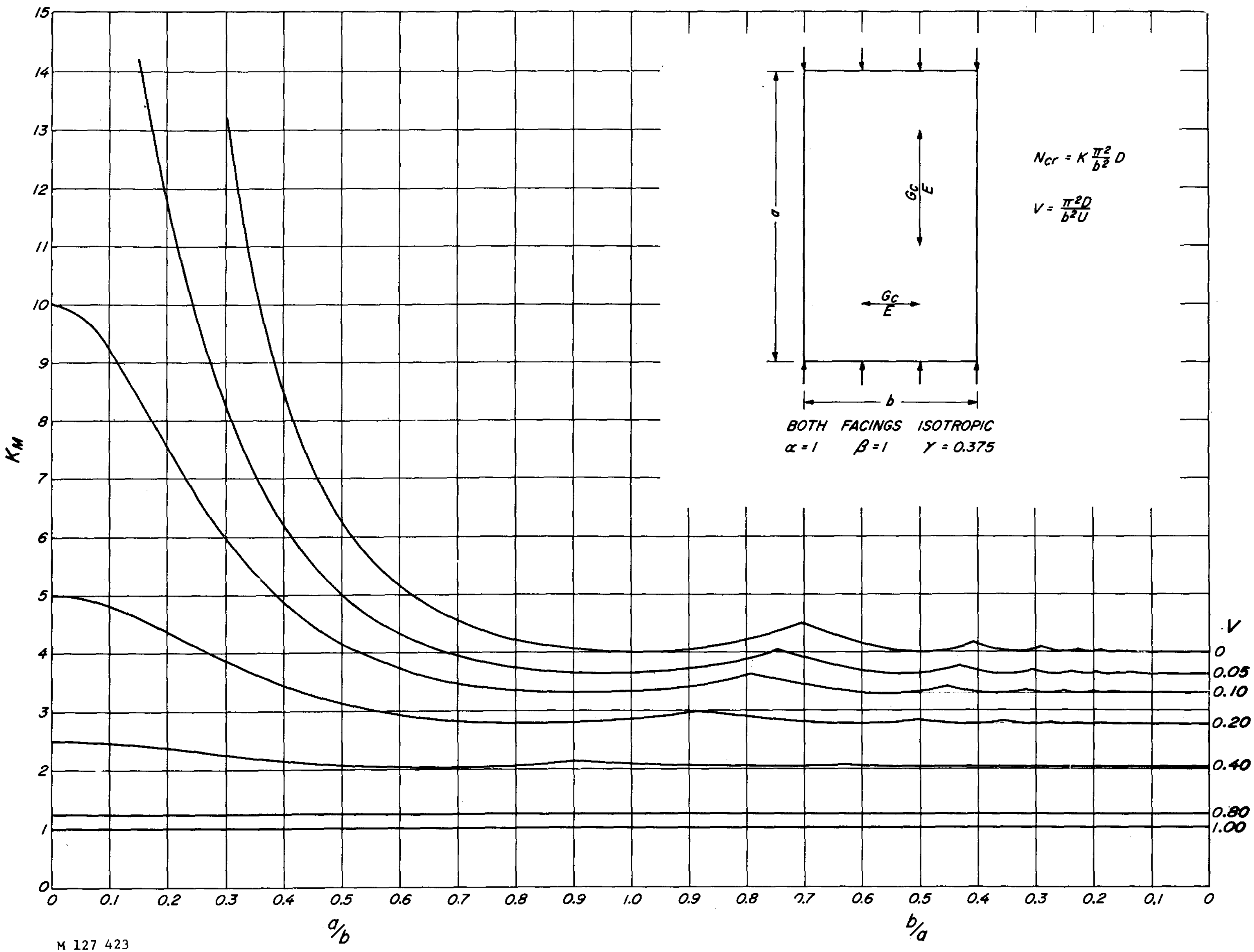
M 127 844

Figure 1.--Notation for dimensions and elastic properties of sandwich panel.



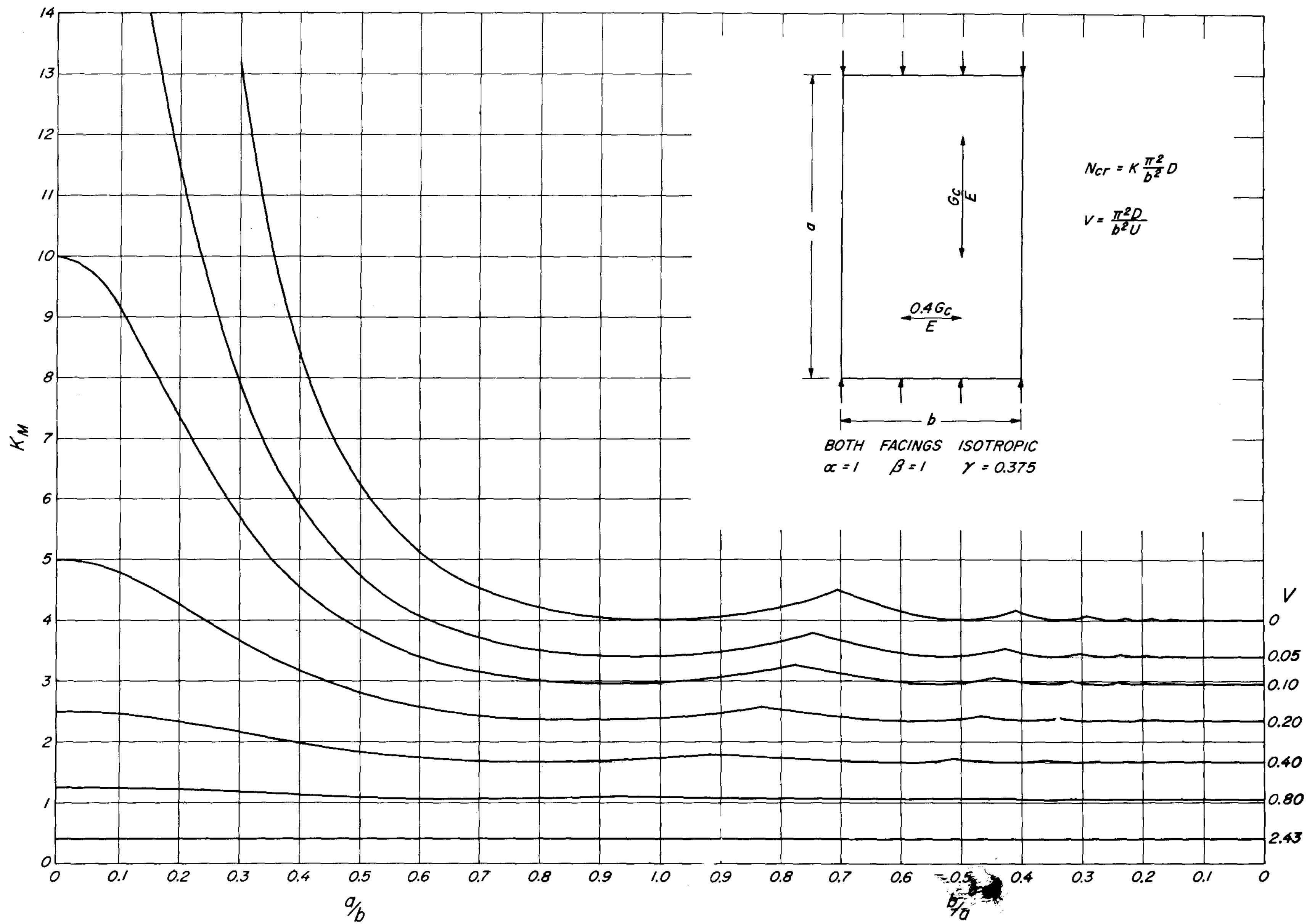
M 127 422

Figure 2.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



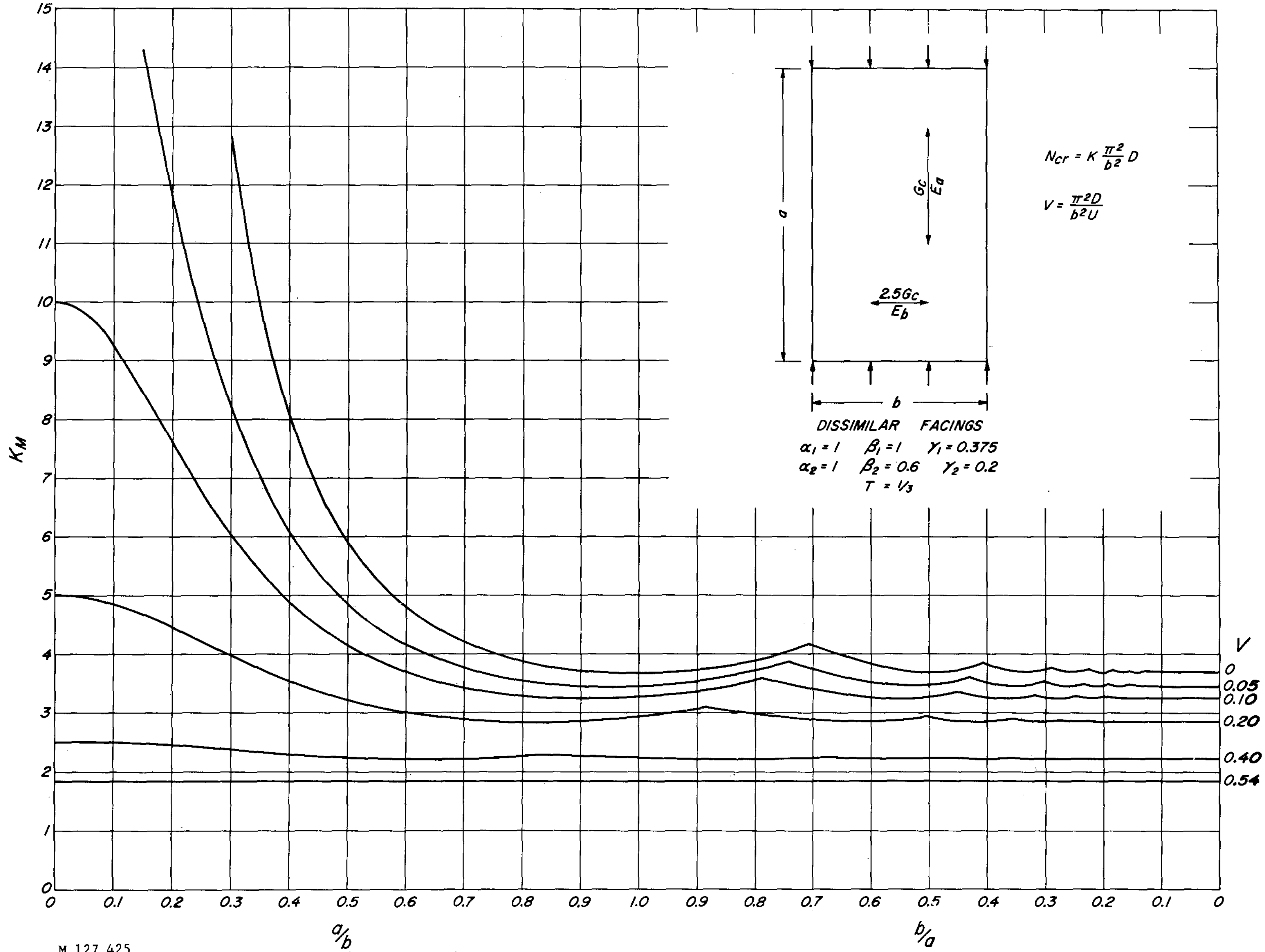
M 127 423

Figure 3.--Buckling coefficients for sandwhich panels in edge compression. All edges simply supported.



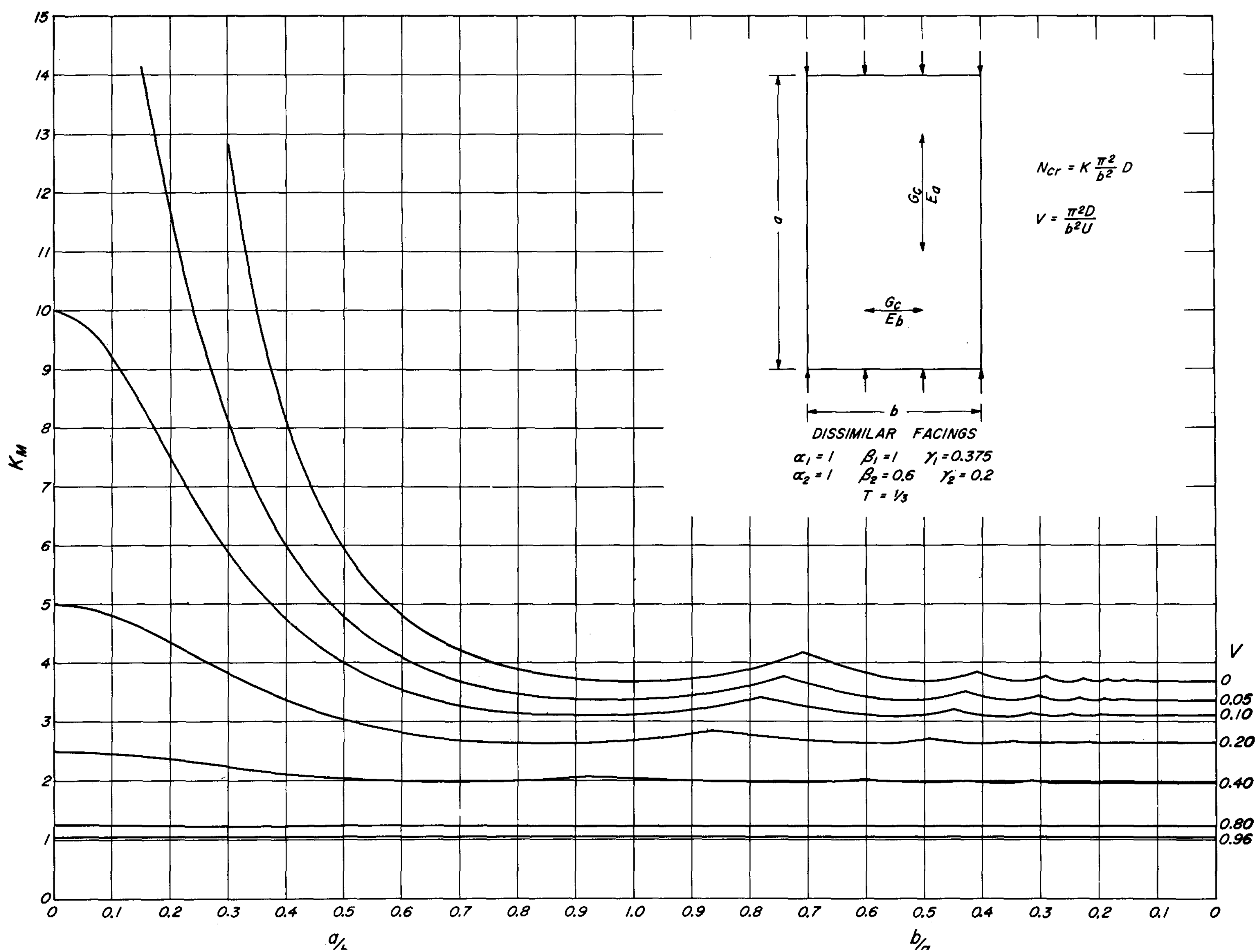
M 127 424

Figure 4.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



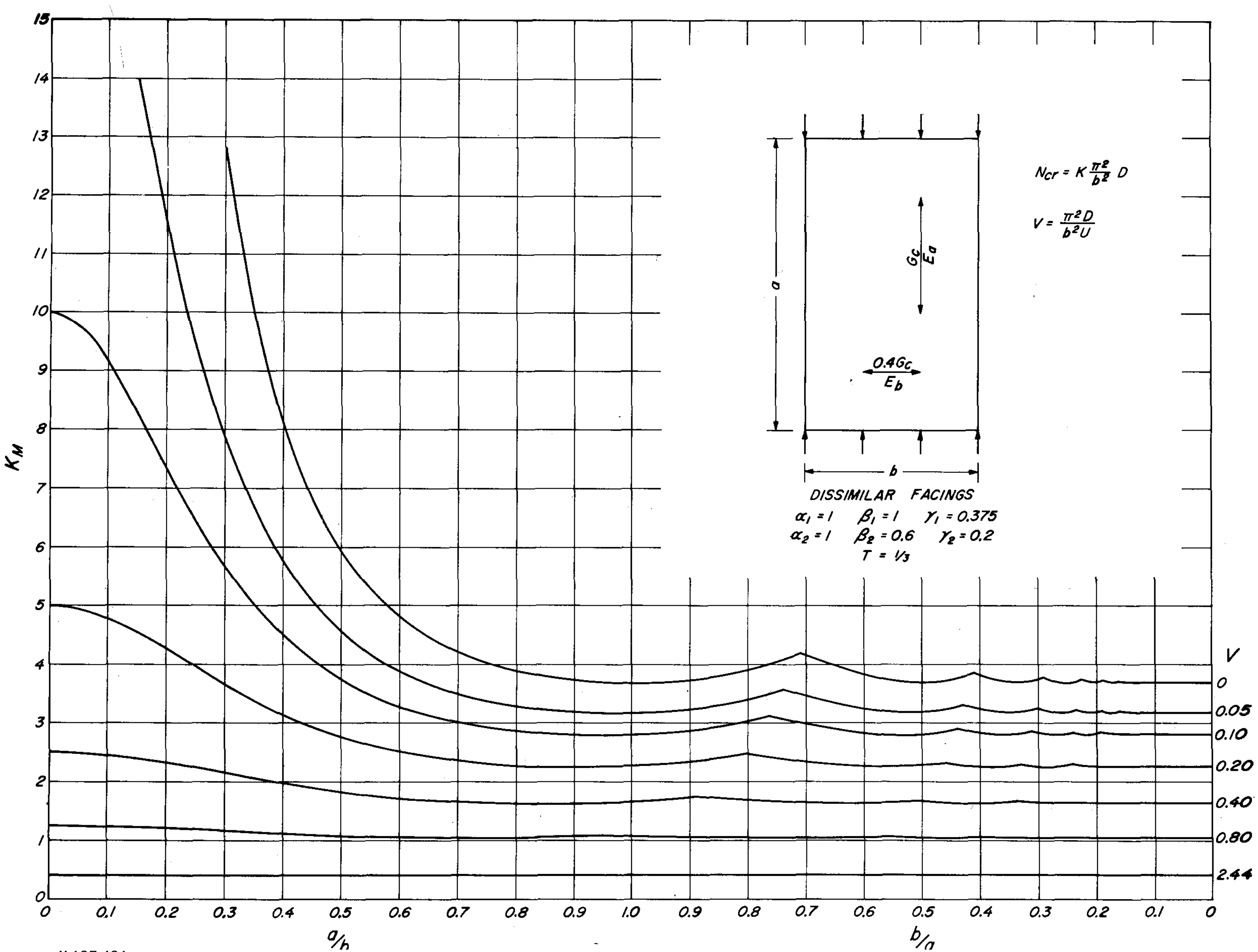
M 127 425

Figure 5.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



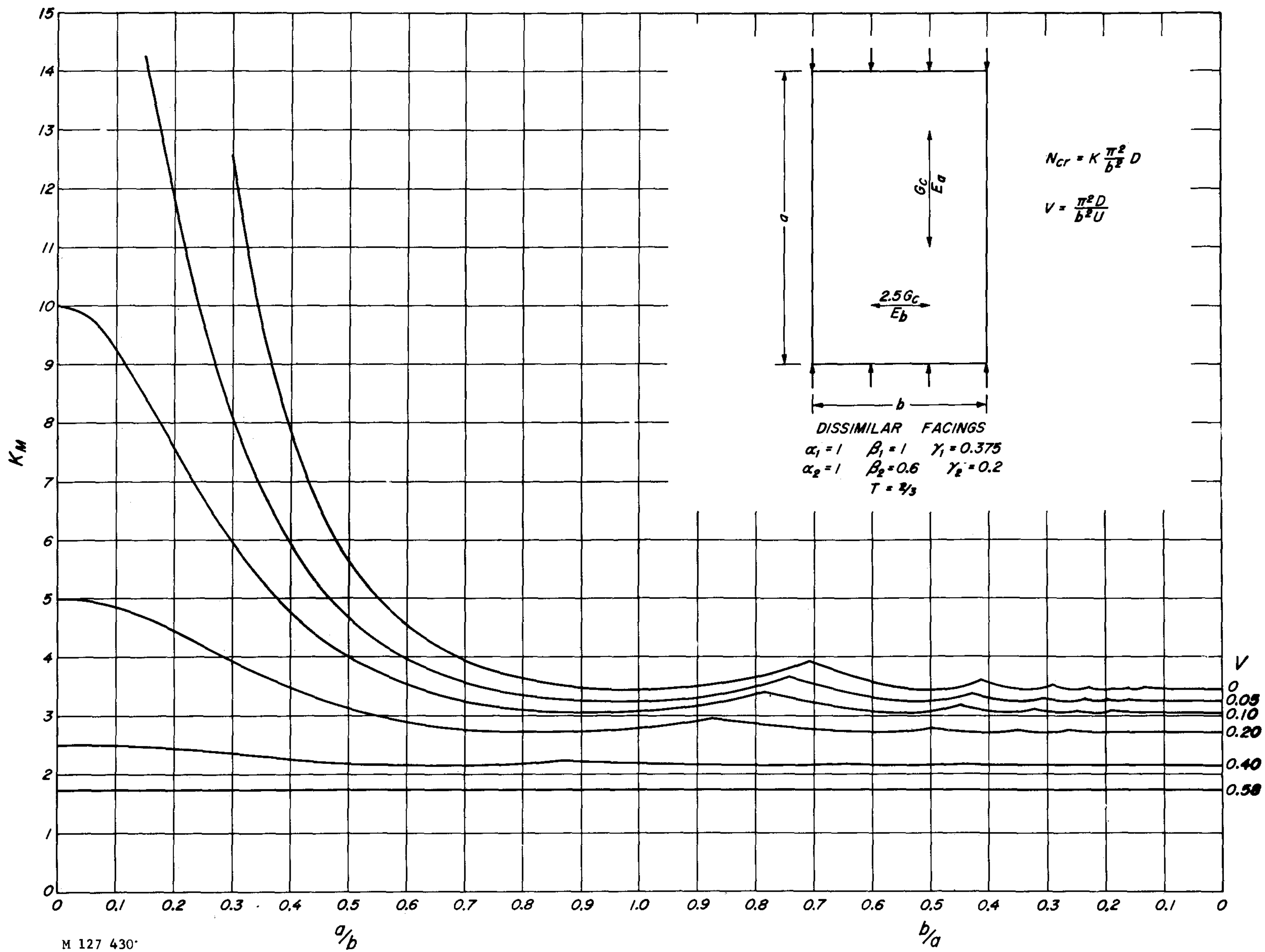
M 127 426

Figure 6.--Buckling coefficients for sandwich panels in edge compression All edges simply supported.



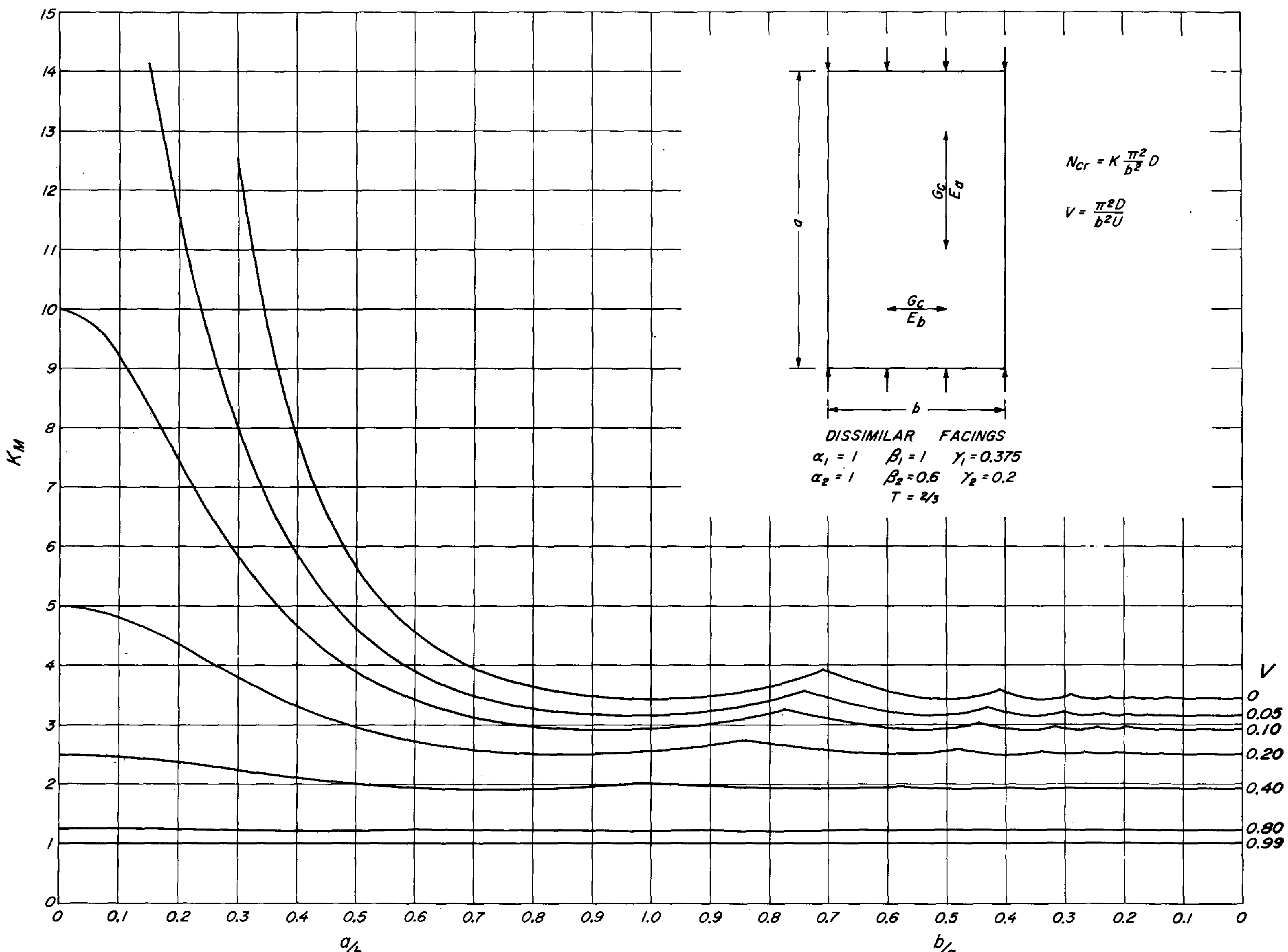
M 127 431

Figure 7.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



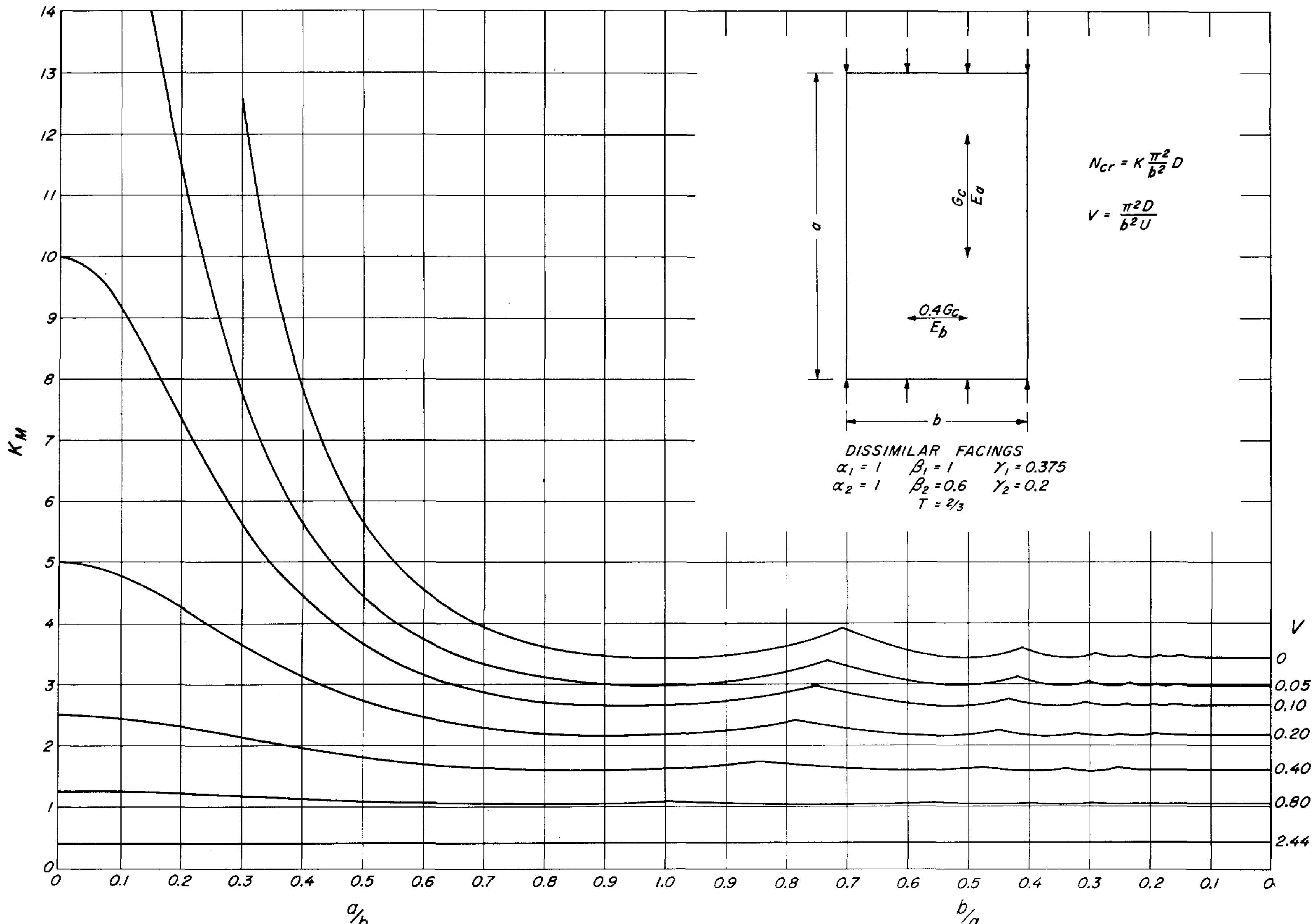
M 127 430

Figure 8.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



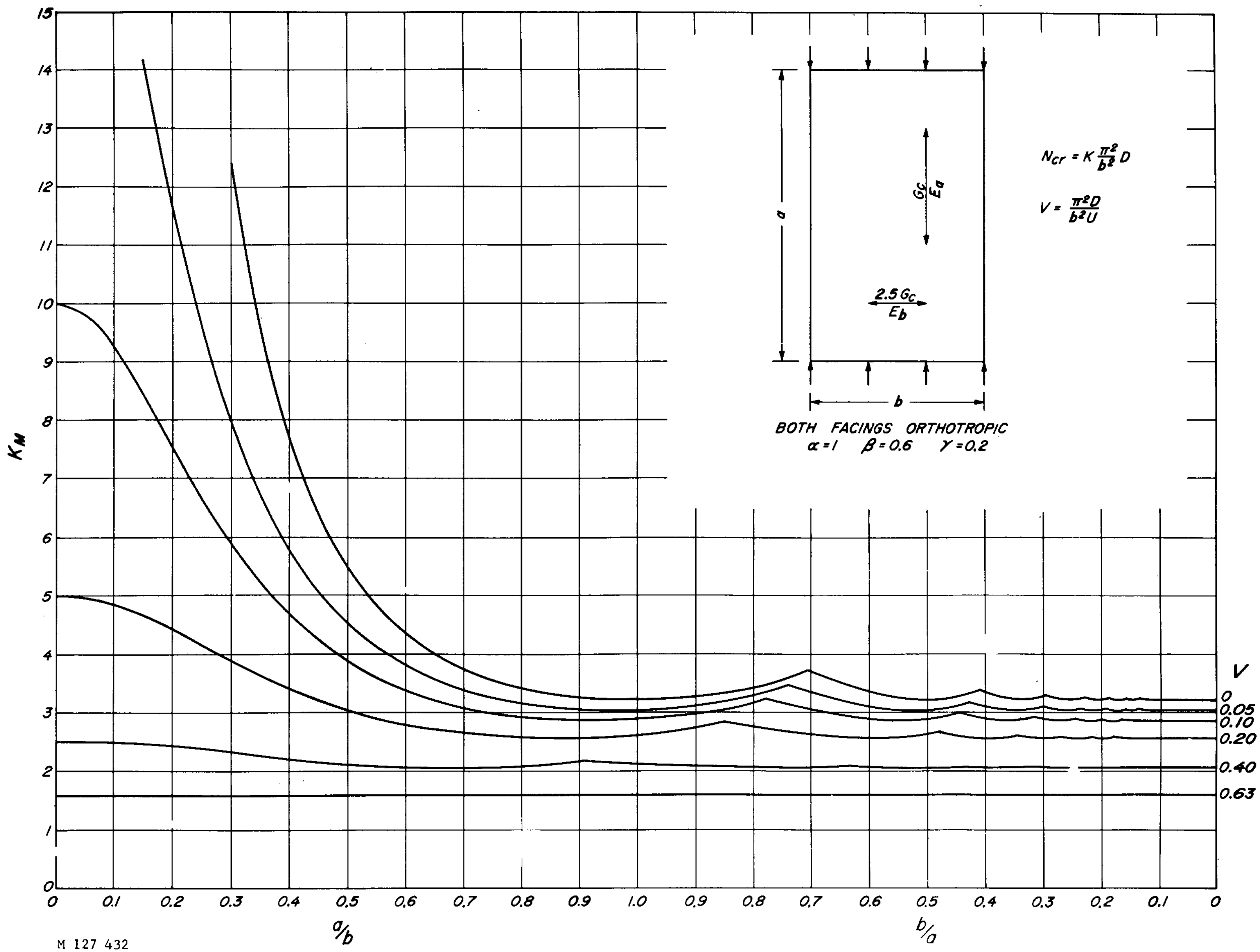
M 127 429

Figure 9.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



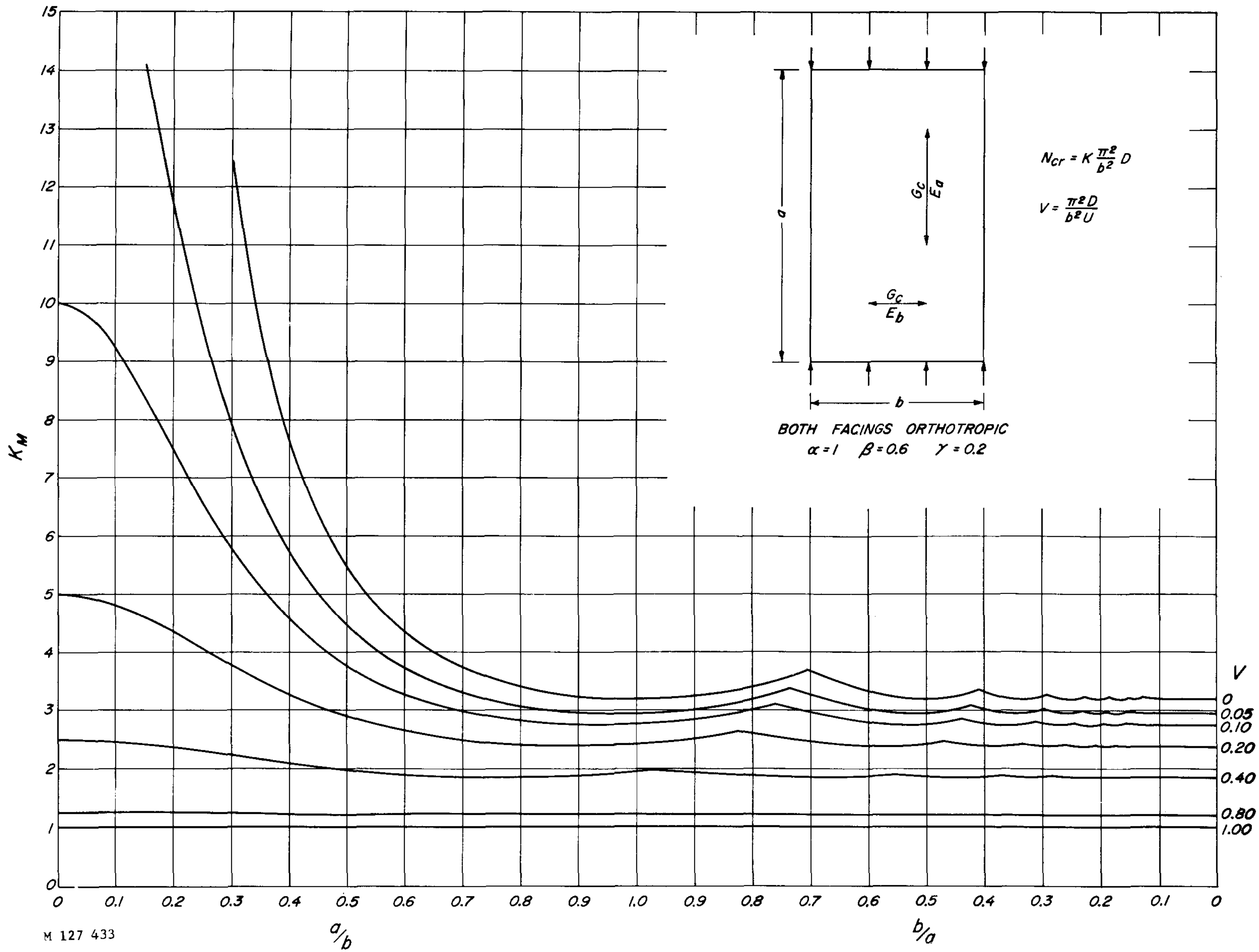
M 127 434

Figure 10.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



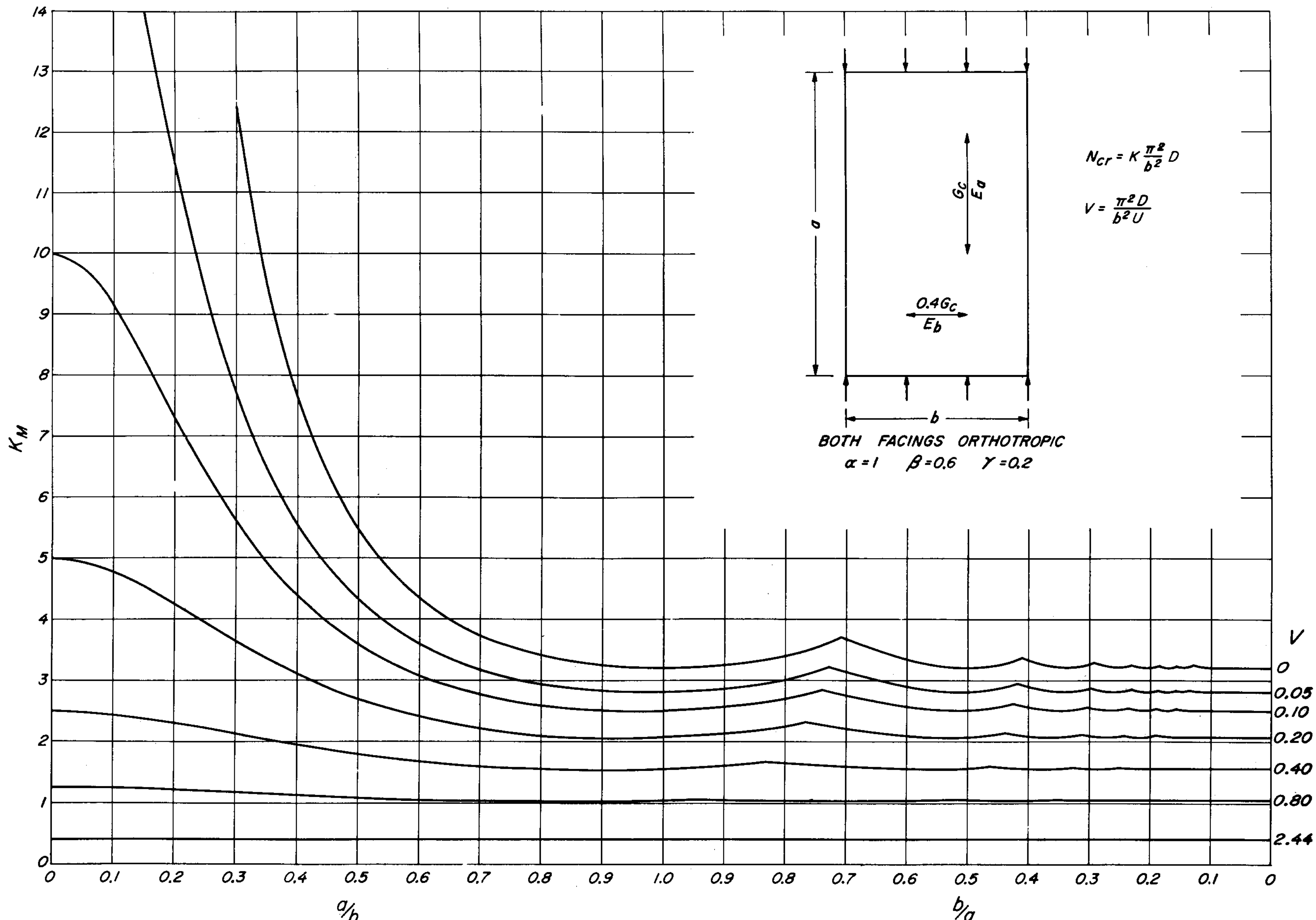
M 127 432

Figure 11.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 433

Figure 12.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 427

Figure 13.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.

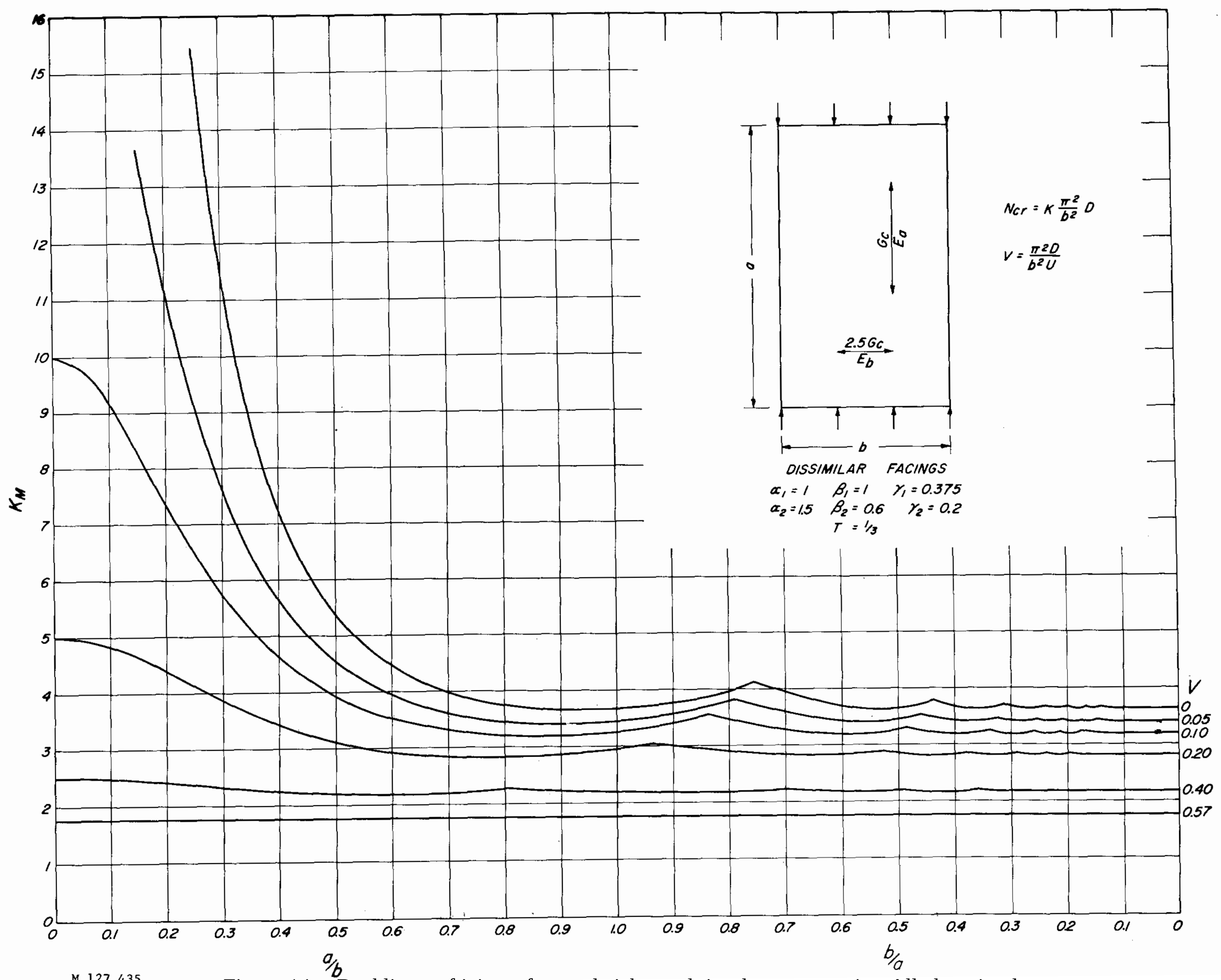


Figure 14.--Bucklingcoefticients for sandwich panels in edge compression. Alledgessimply supported.

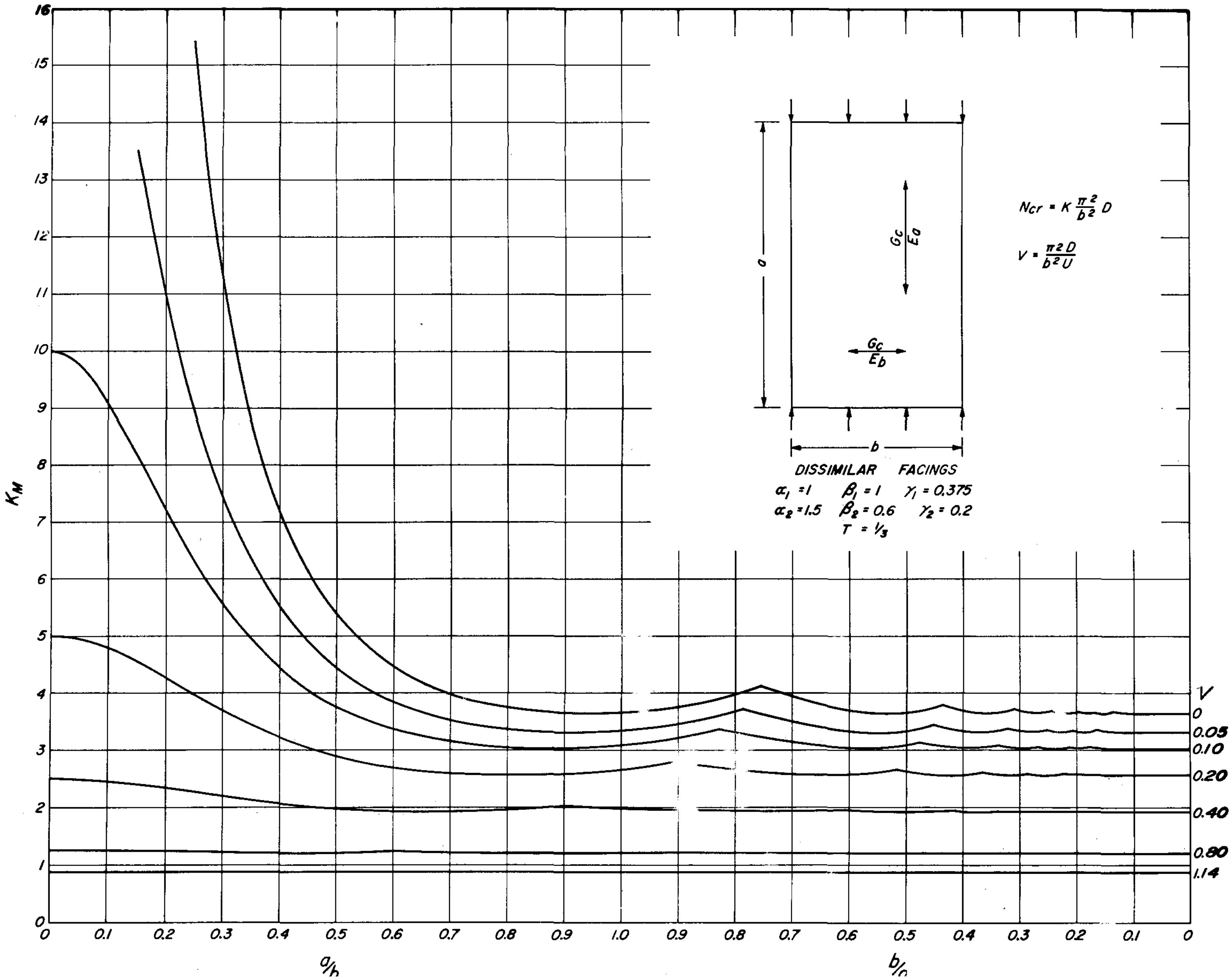
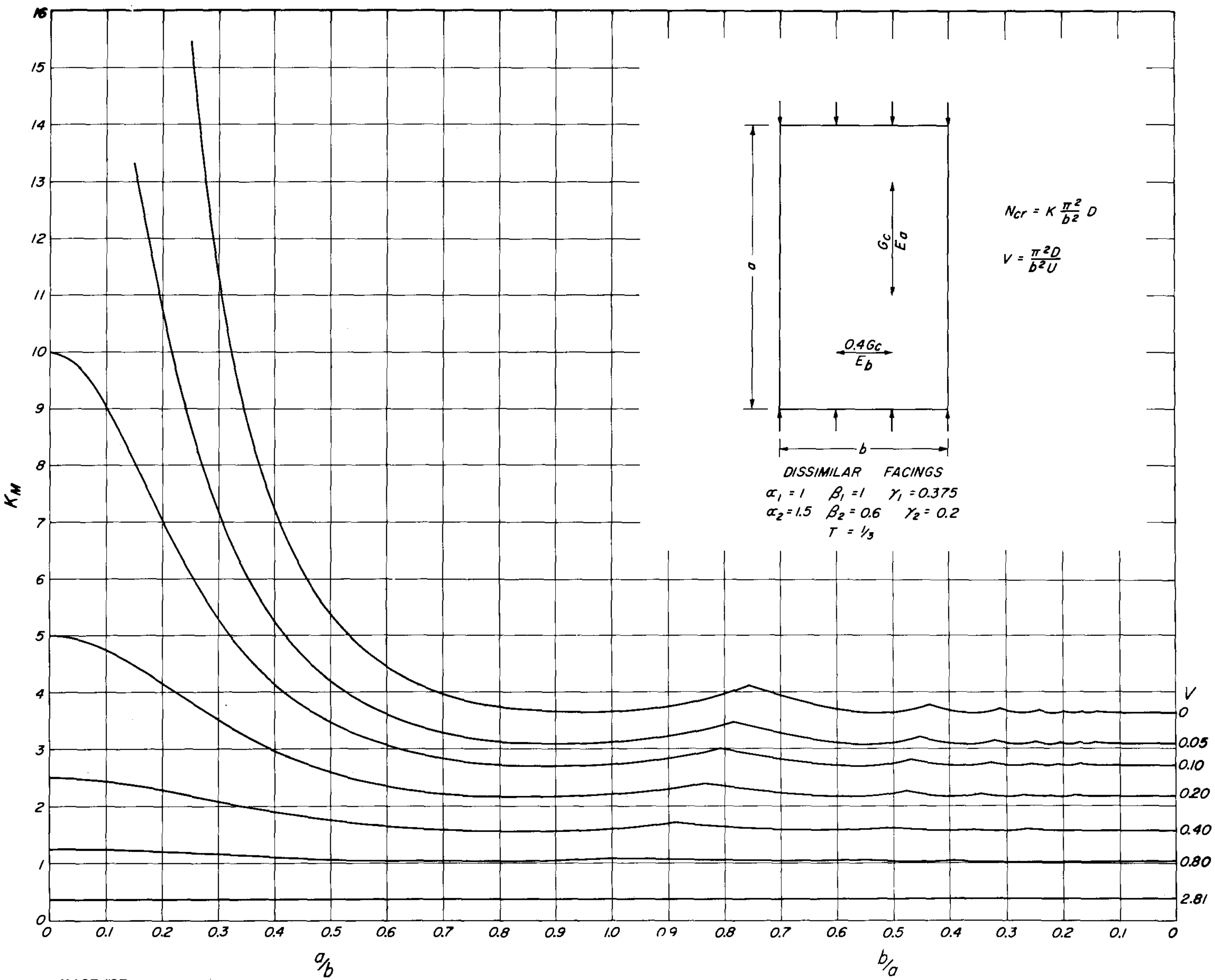
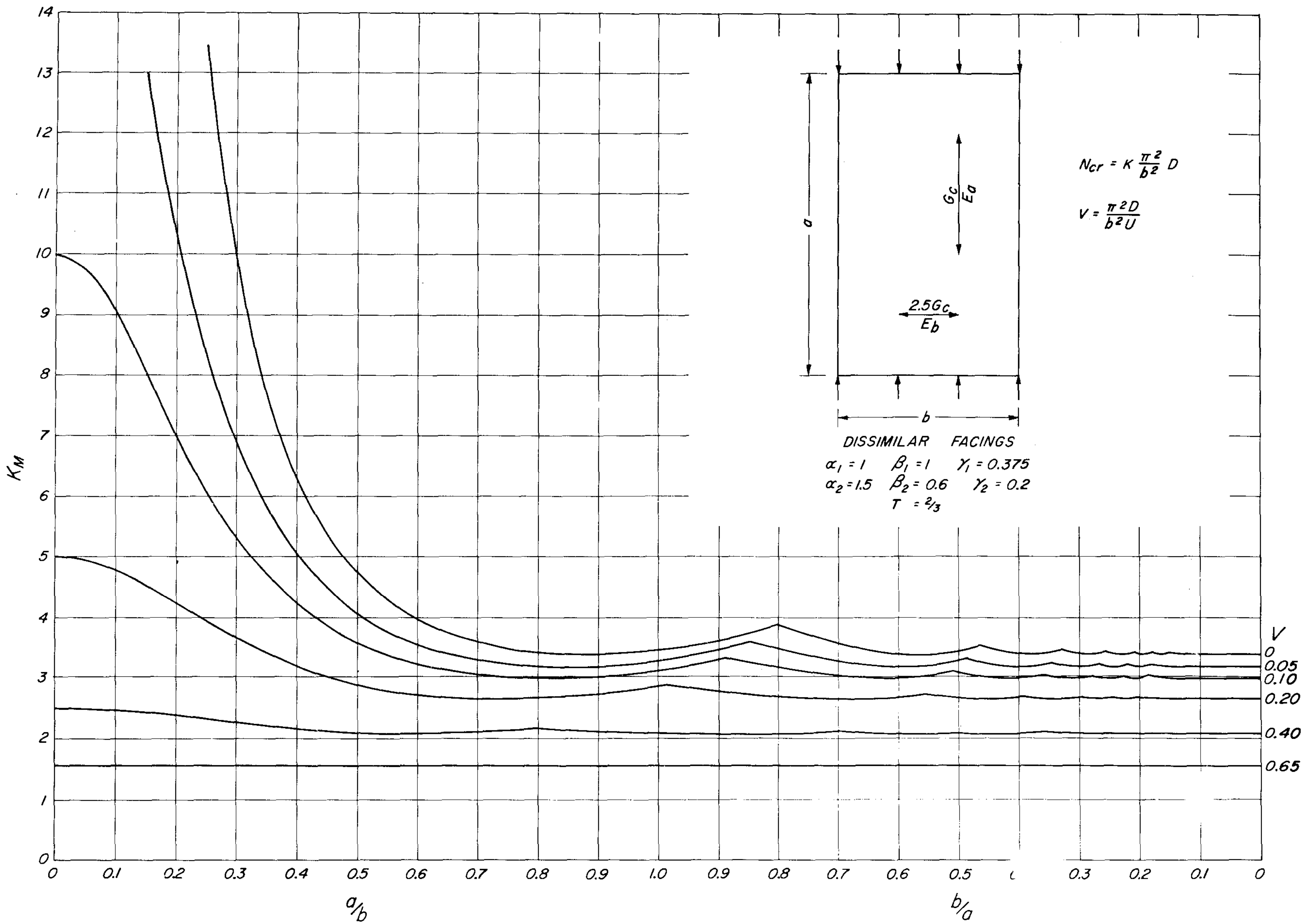


Figure 15.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



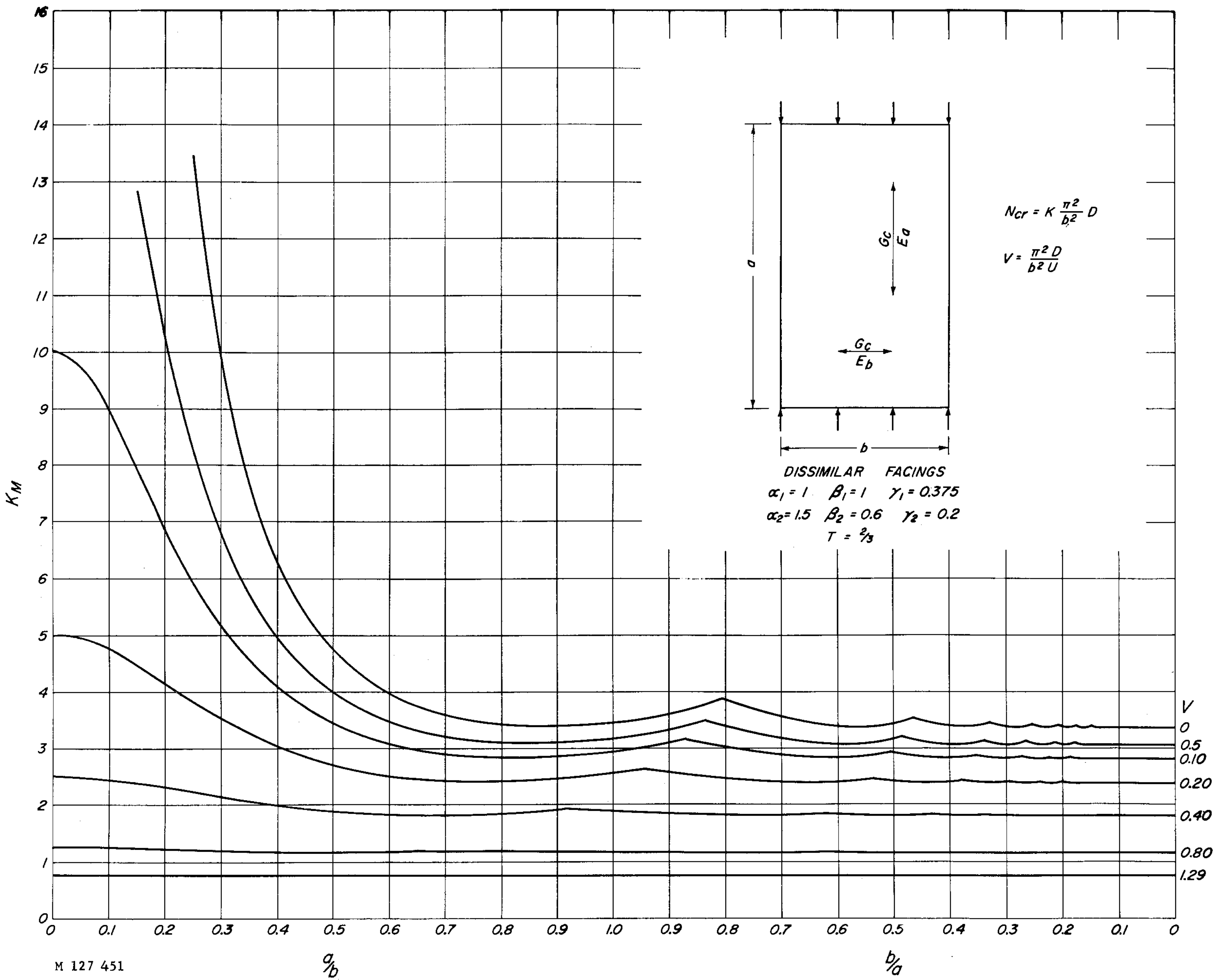
M127 437

Figure 16.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 438

Figure 17.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 451

Figure 18.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.

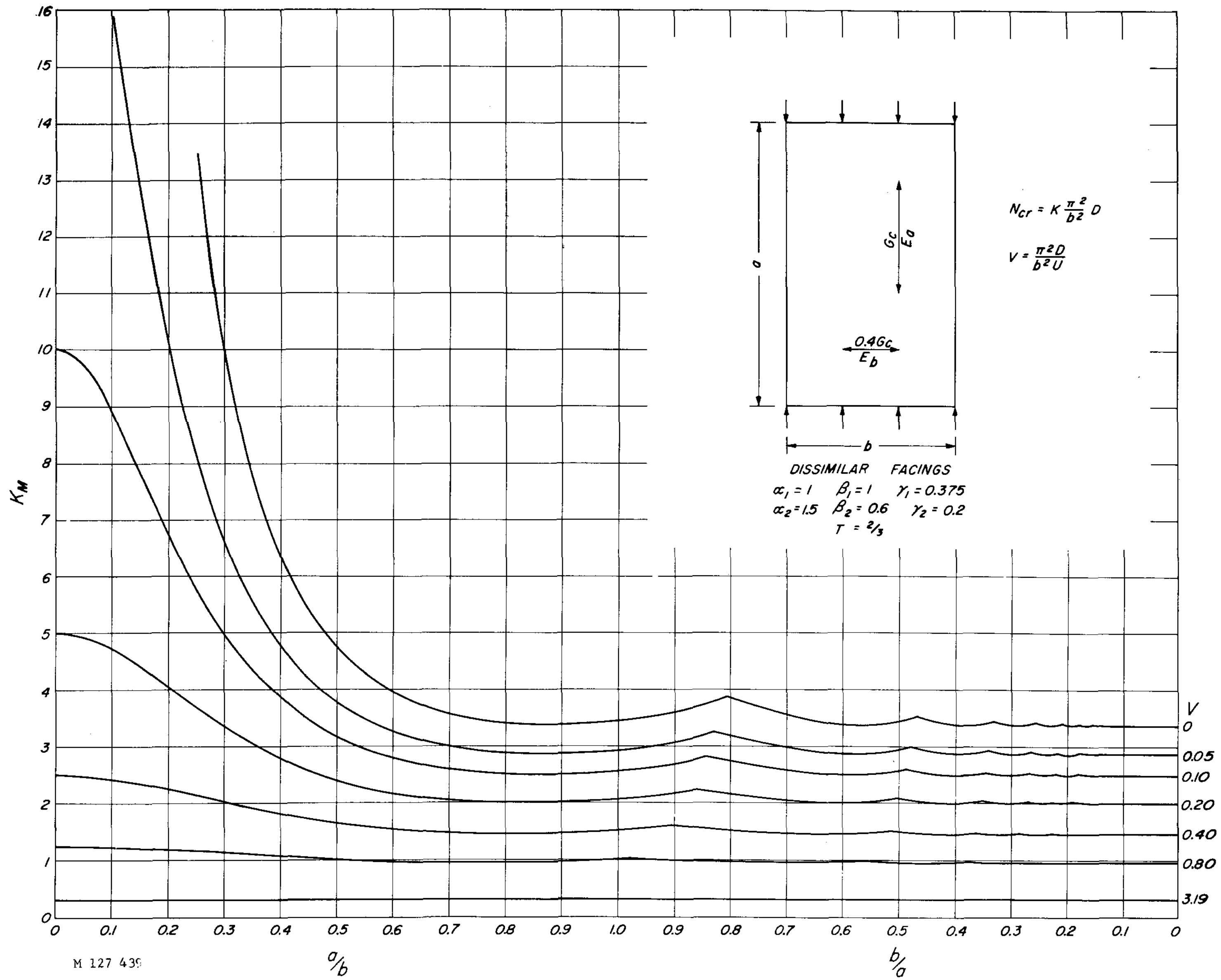
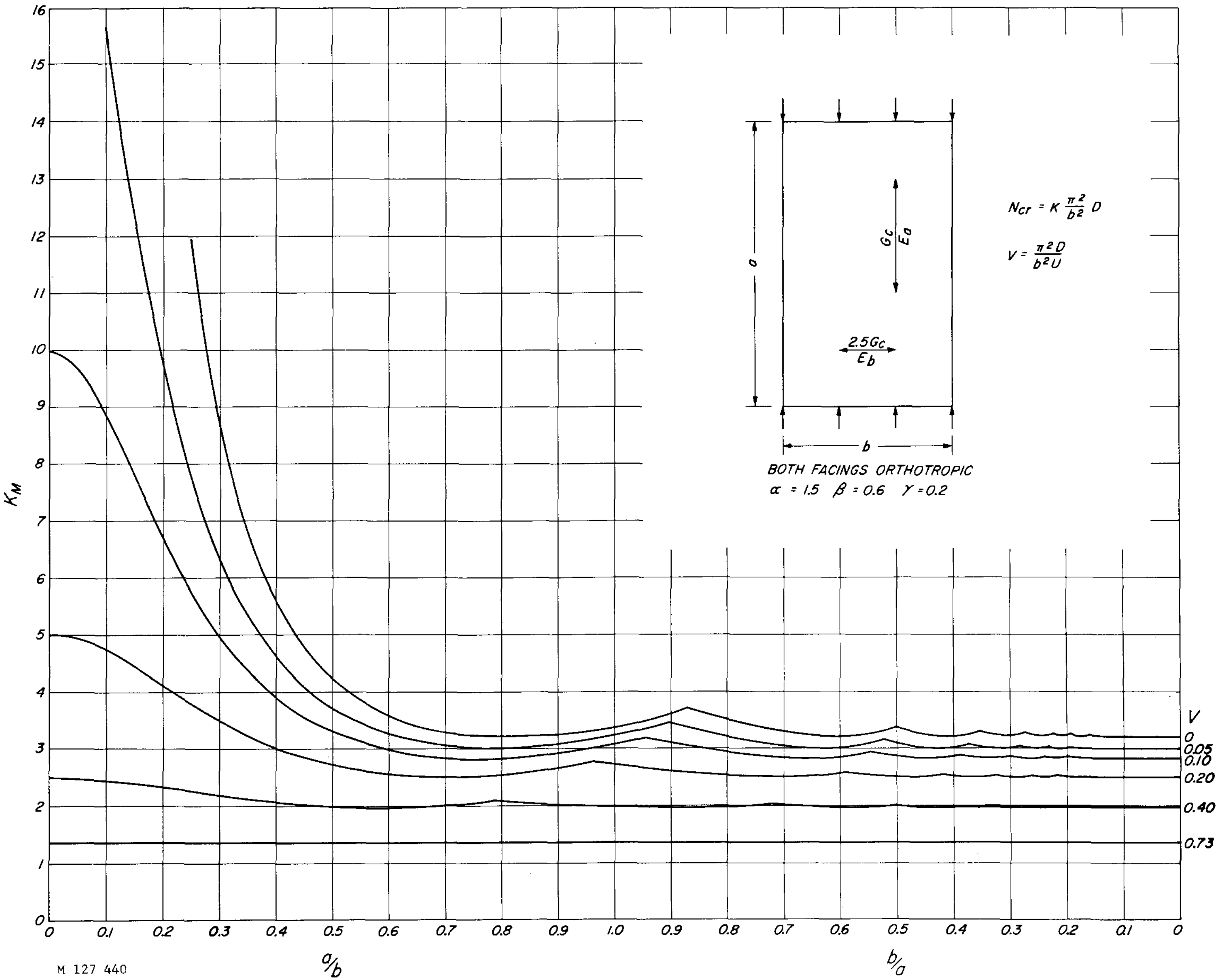
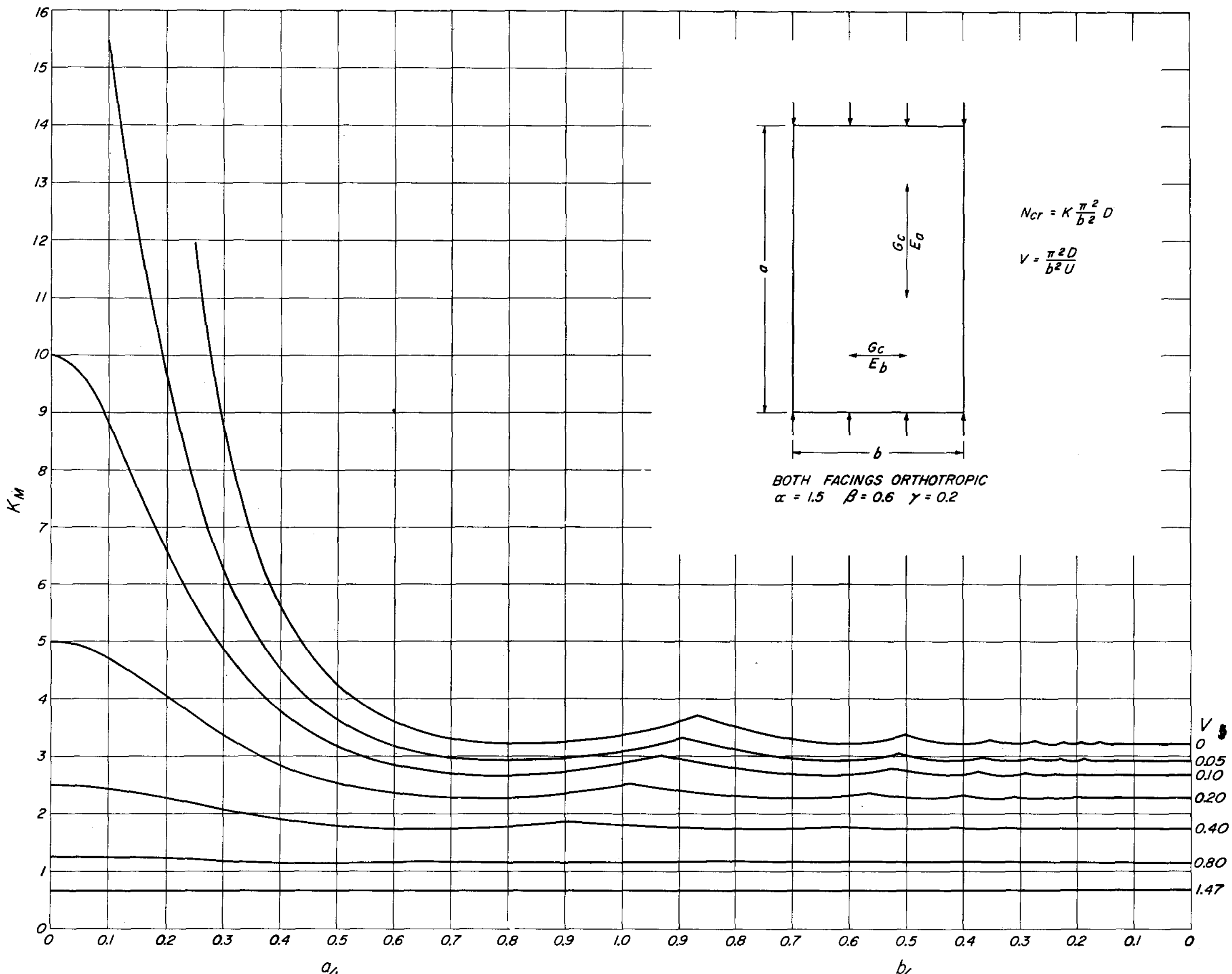


Figure 19.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



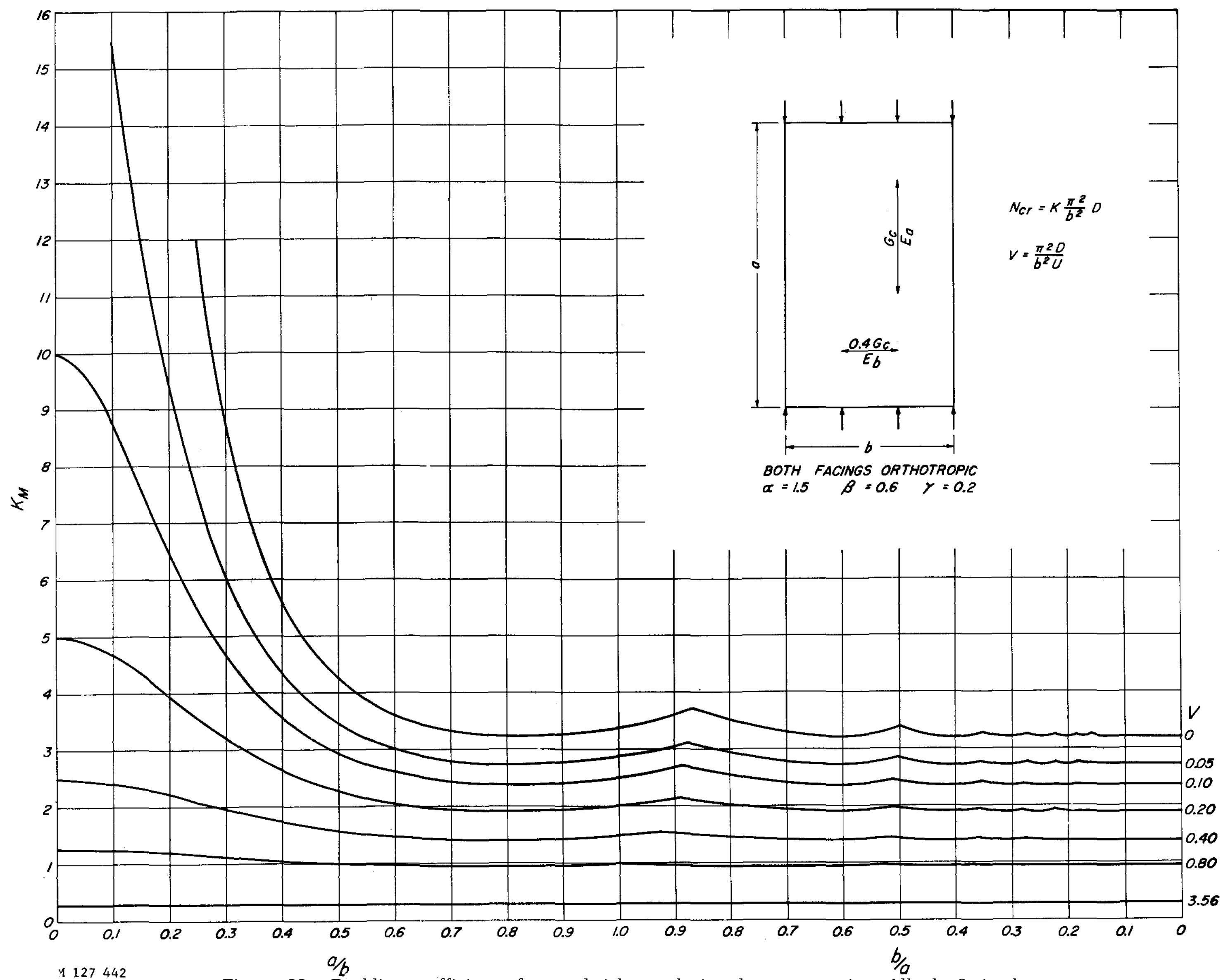
M 127 440

Figure 20.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



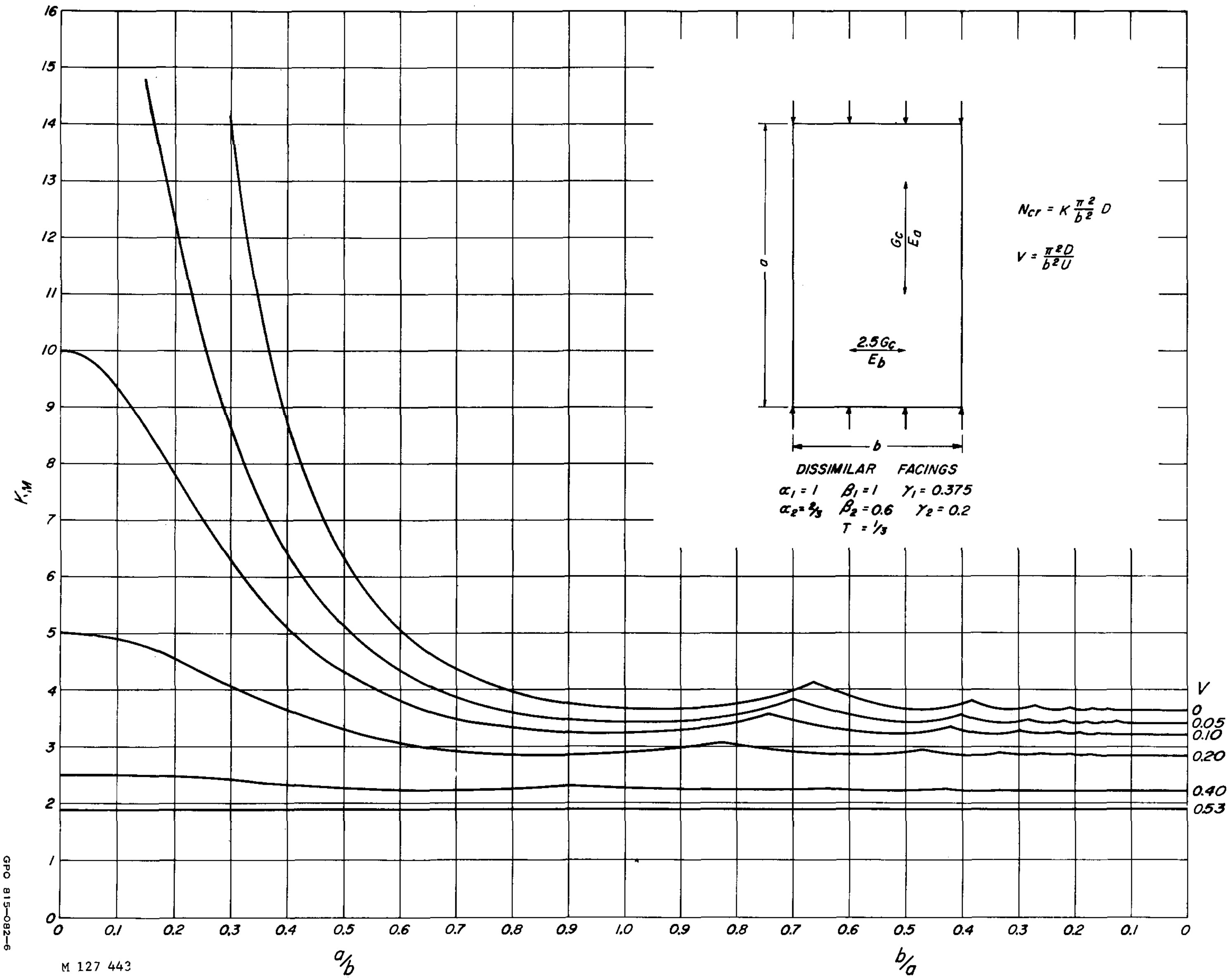
M 127 441

Figure 21.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 442

Figure 22.--Buckling coefficients for sandwich panels in edge compression. All edge6 simply supported.



M 127 443

Figure 23.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.

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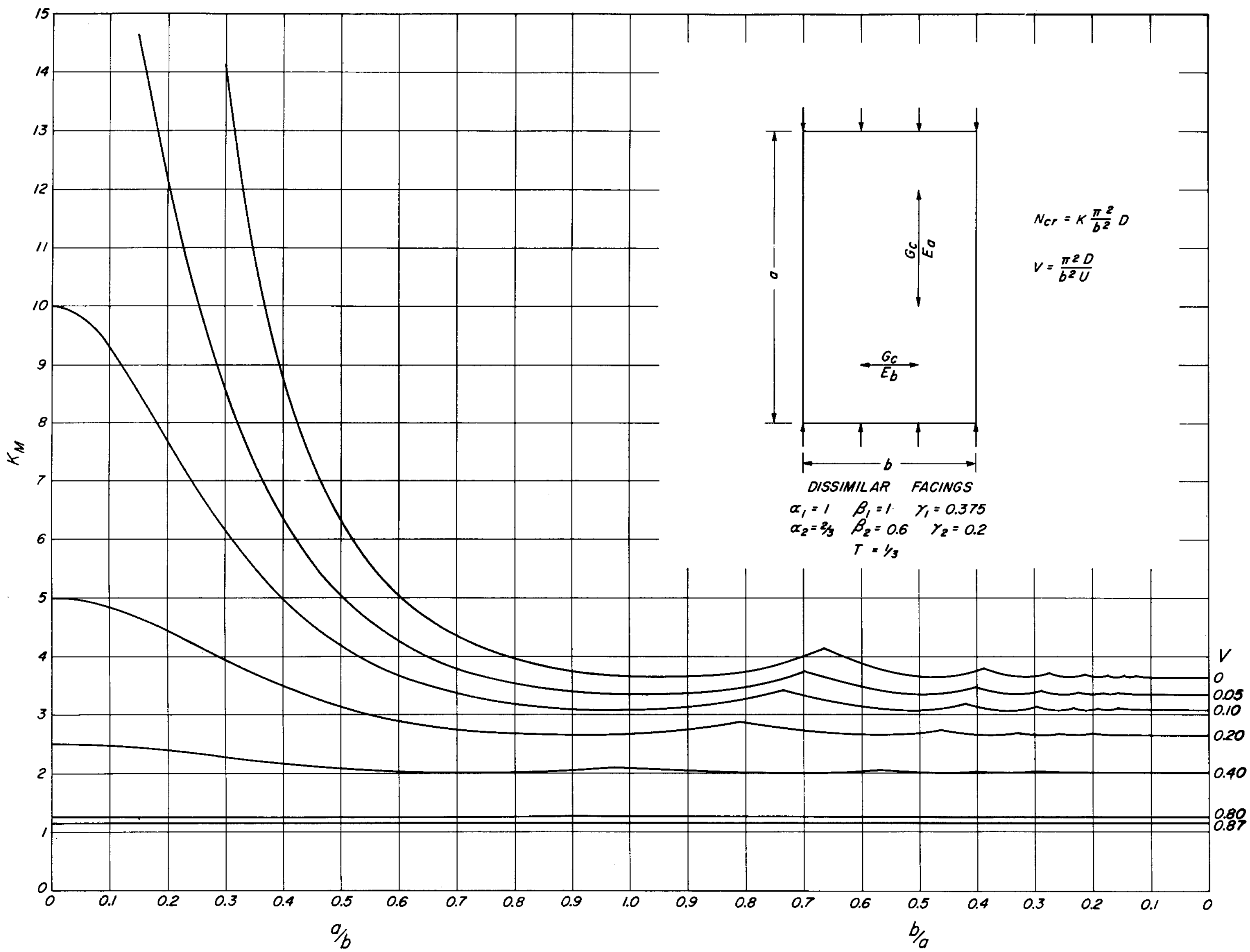
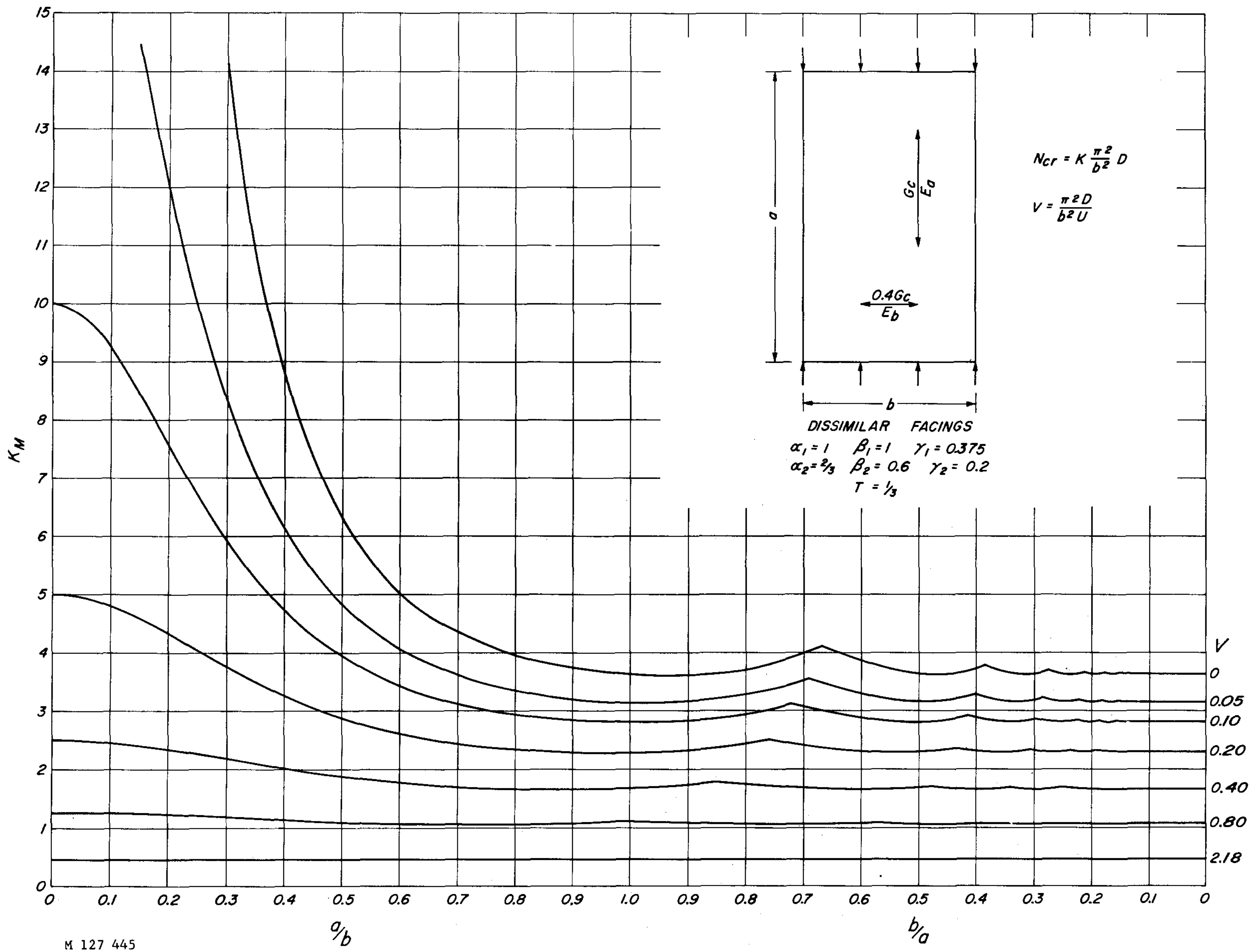
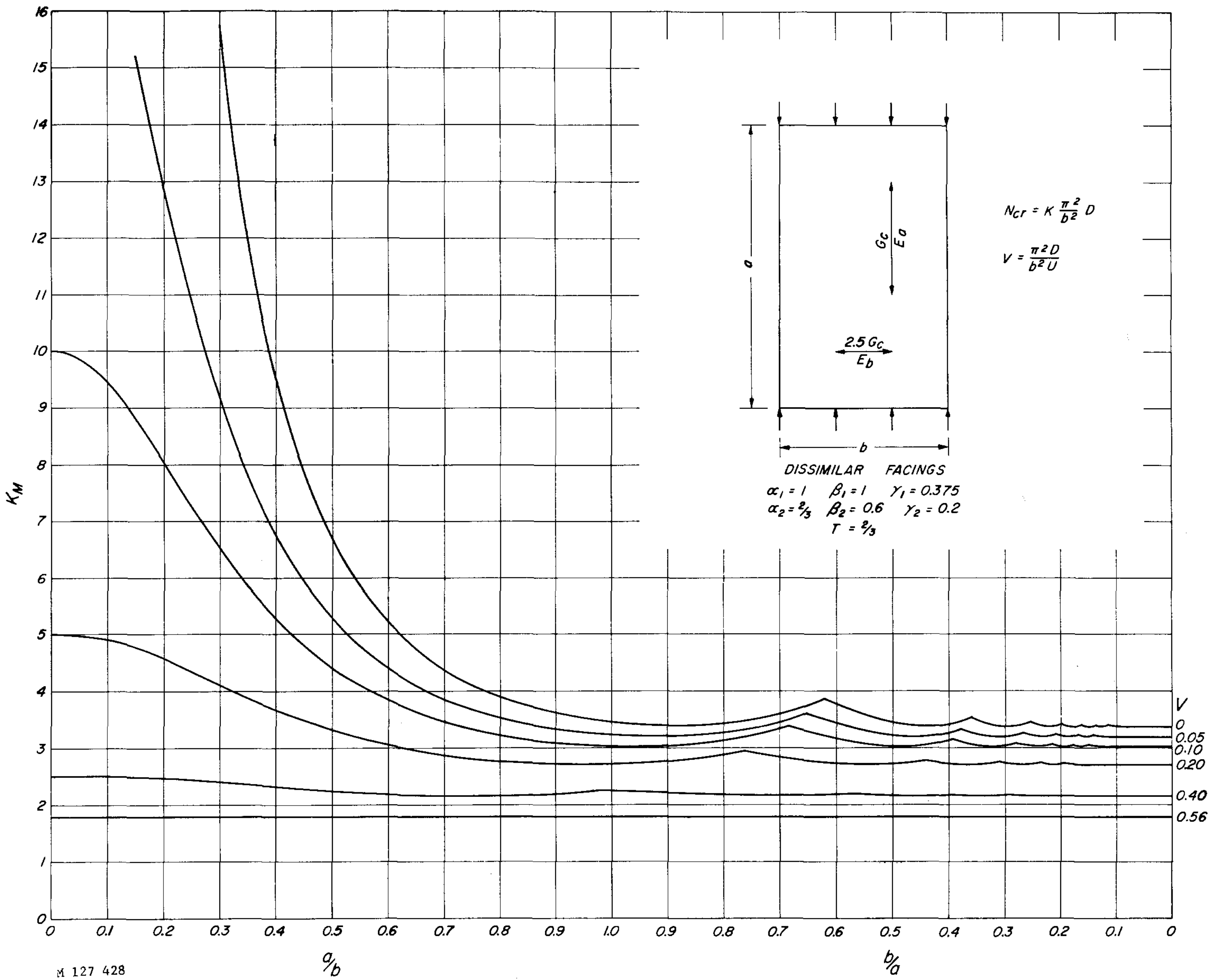


Figure 24.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



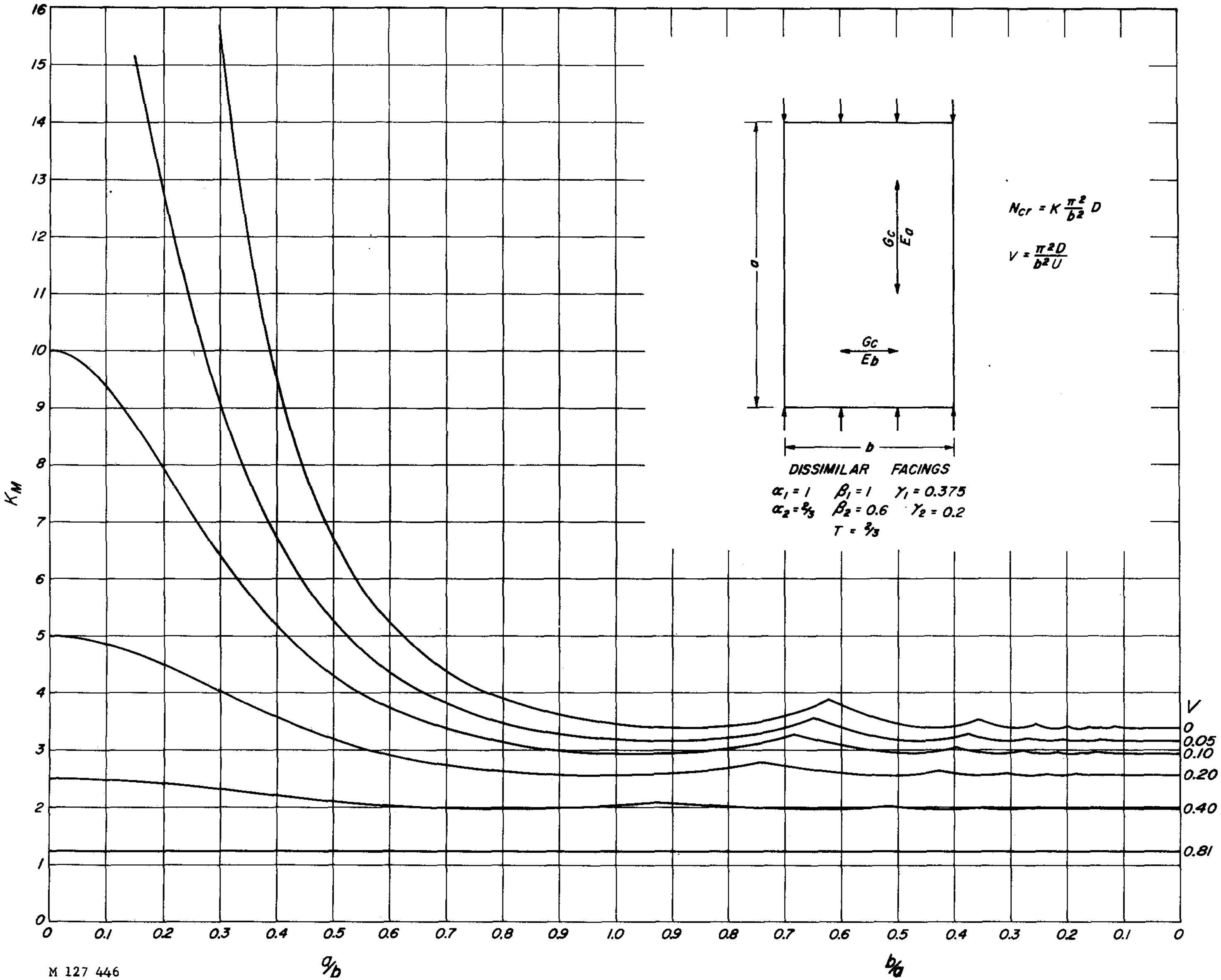
M 127 445

Figure 25.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 428

Figure 26.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



M 127 446

Figure 27.--Buckling coefficients for sandwich panels in edge compression, All edges simply supported.

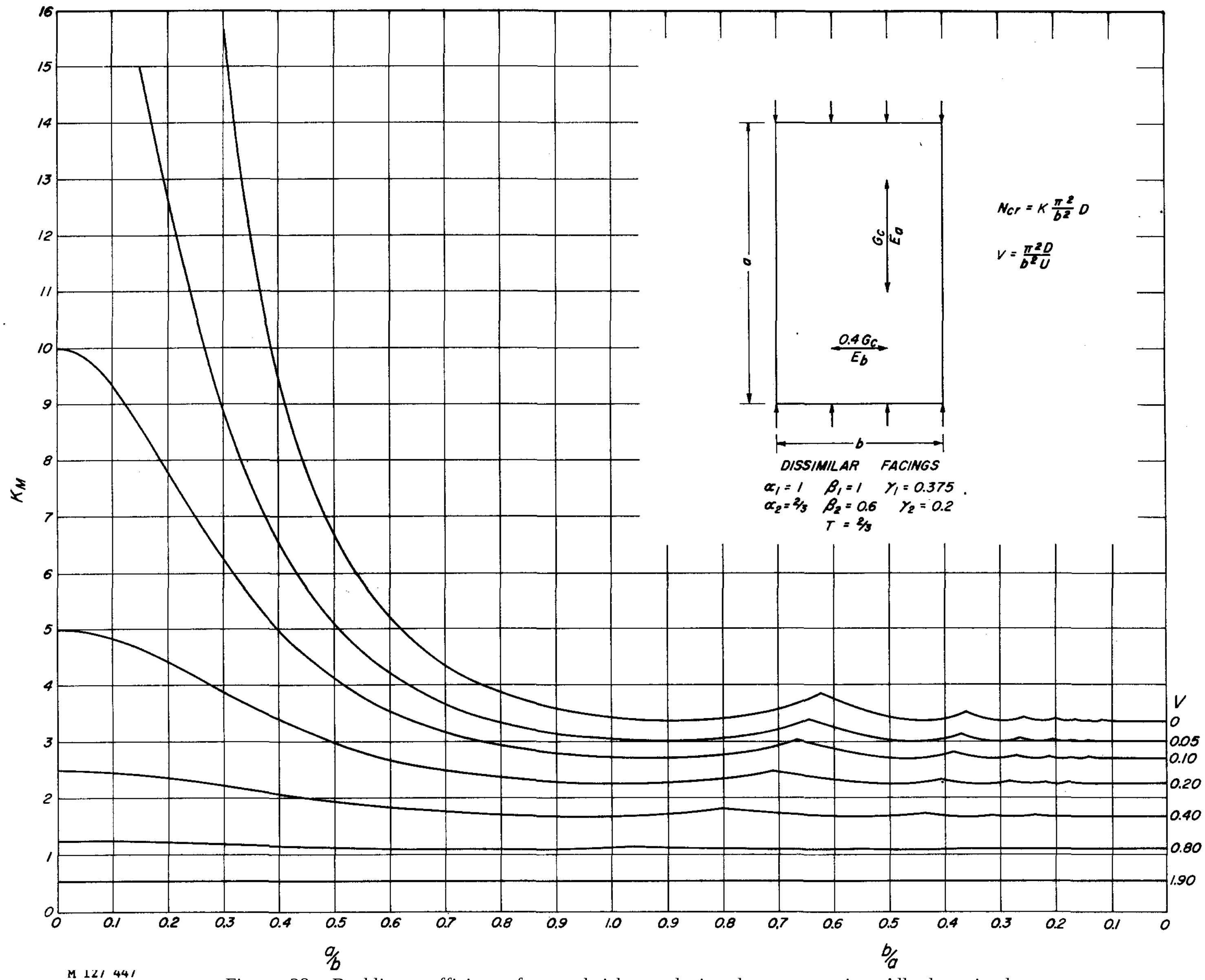


Figure 28.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.

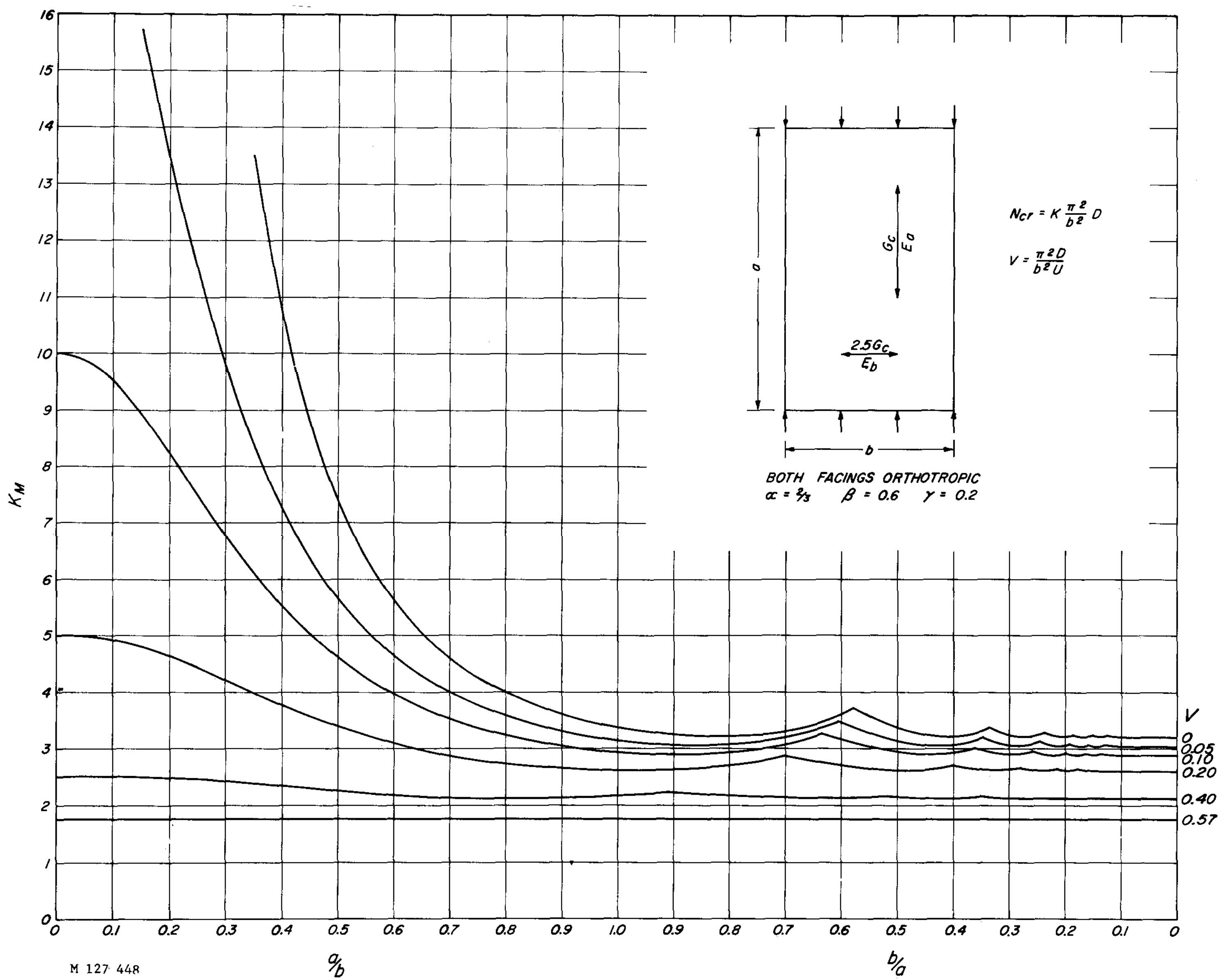
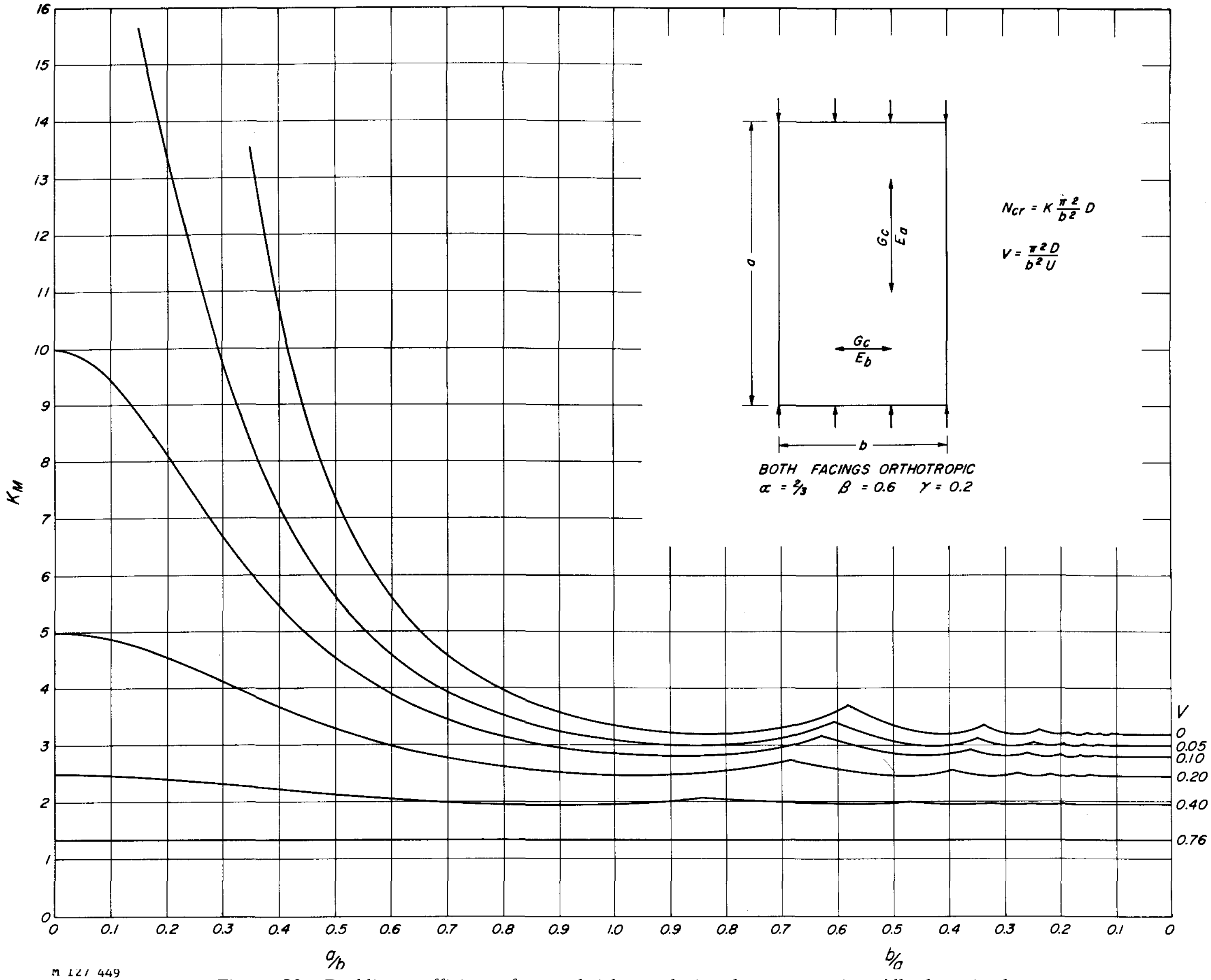
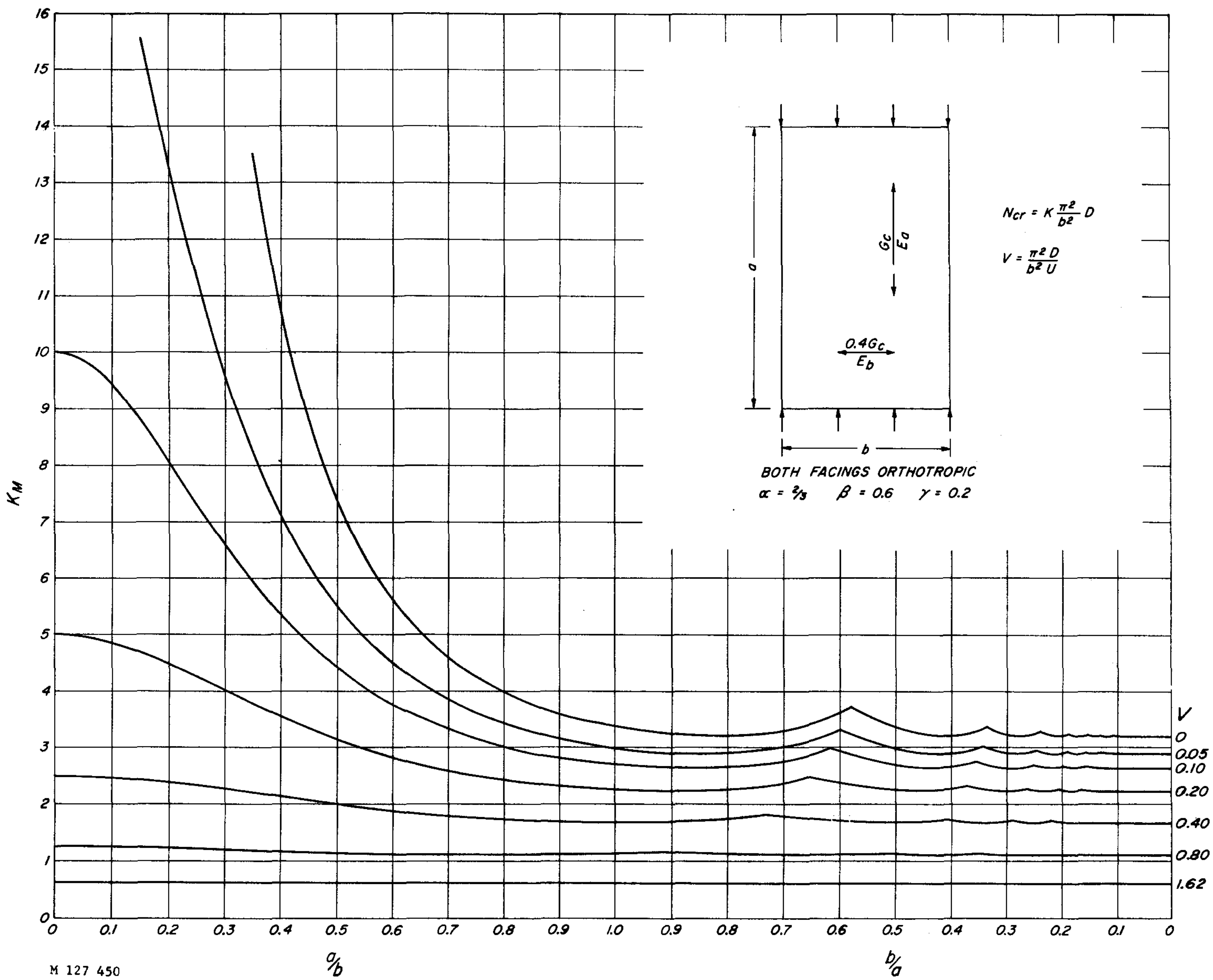


Figure 29.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported



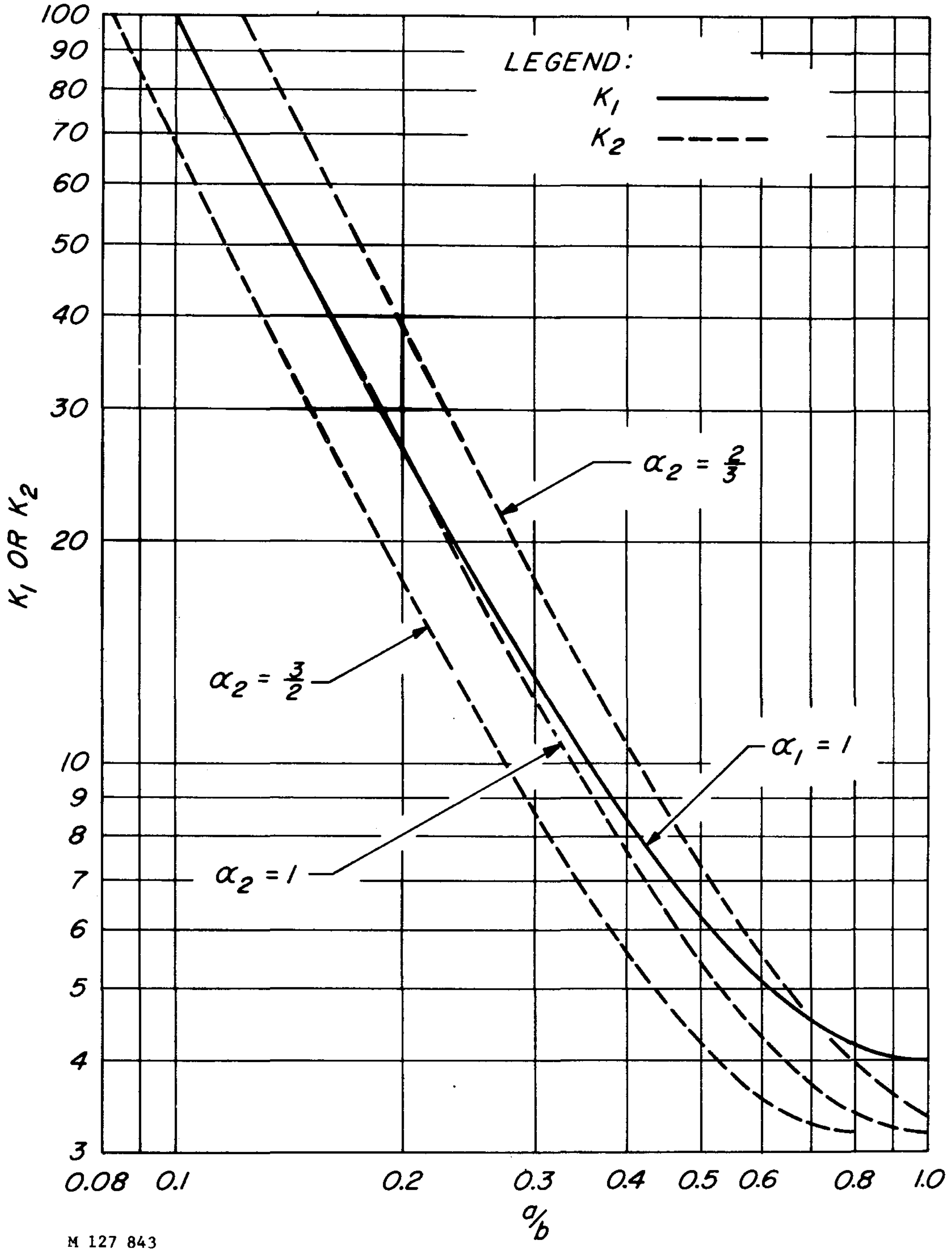
M 127 449

Figure 30.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



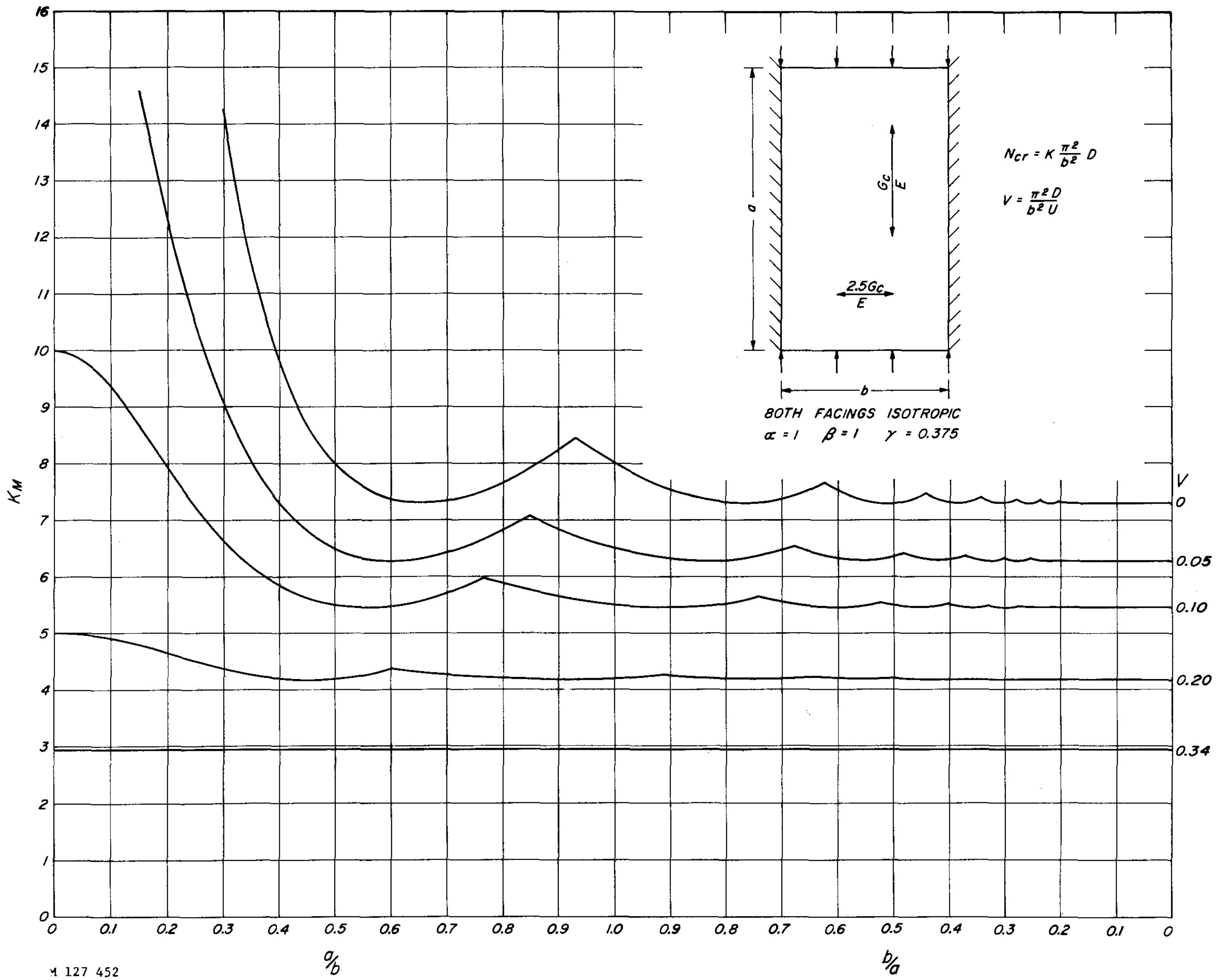
M 127 450

Figure 31.--Buckling coefficients for sandwich panels in edge compression. All edges simply supported.



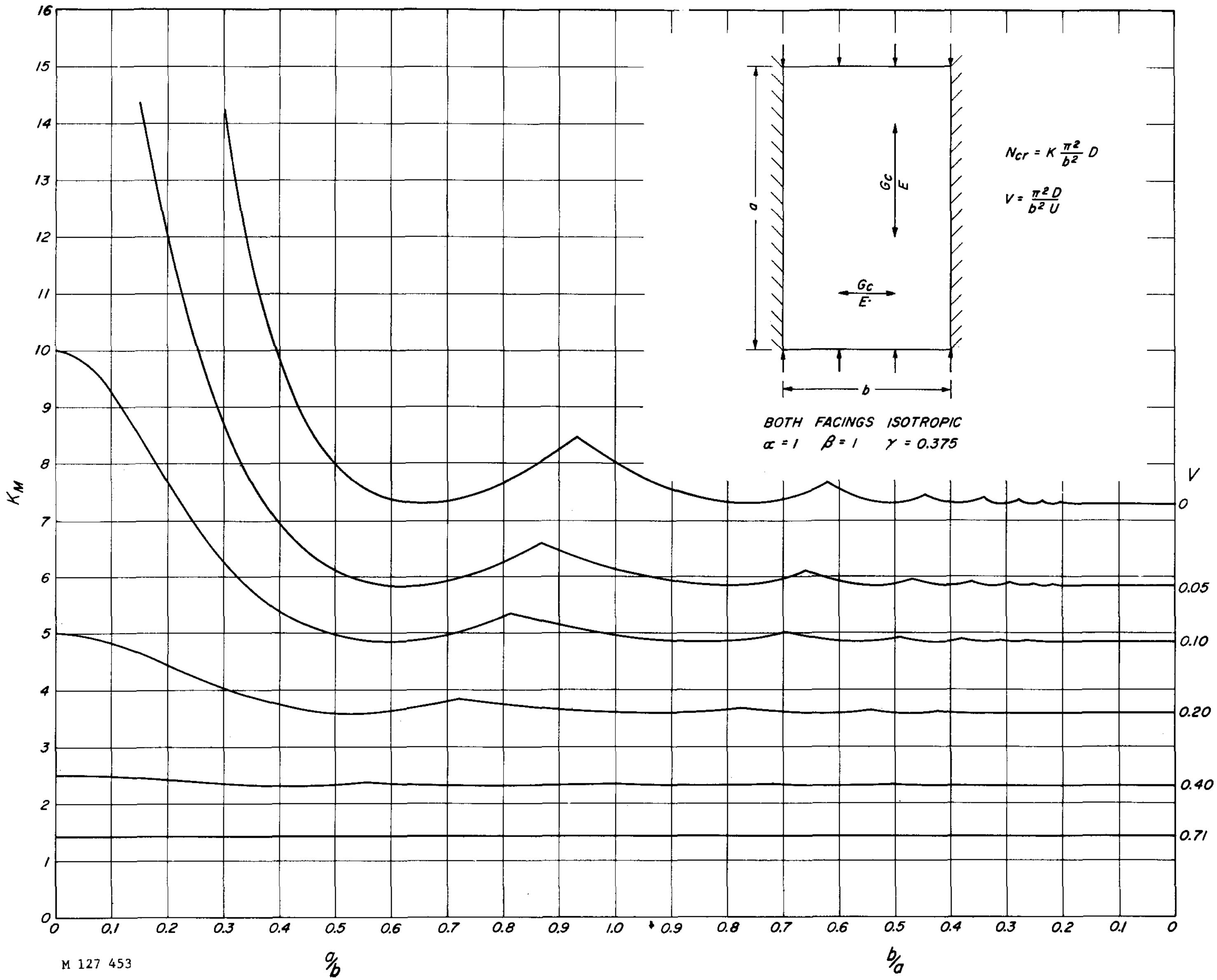
M 127 843

Figure 32.--Values of $\underline{K_1}$ and $\underline{K_2}$, (n = 1), for sandwich panels with all edges simply supported. $\beta_1 = 1$, $\lambda_1 = 3/8$. $\beta_2 = 0.6$, $\lambda_2 = 0.2$.



M 127 452

Figure 33.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 453

Figure 34.--Buckling coefficients for sandwich panels in edge compression. Loaded edges si. supported, other edges clamped.

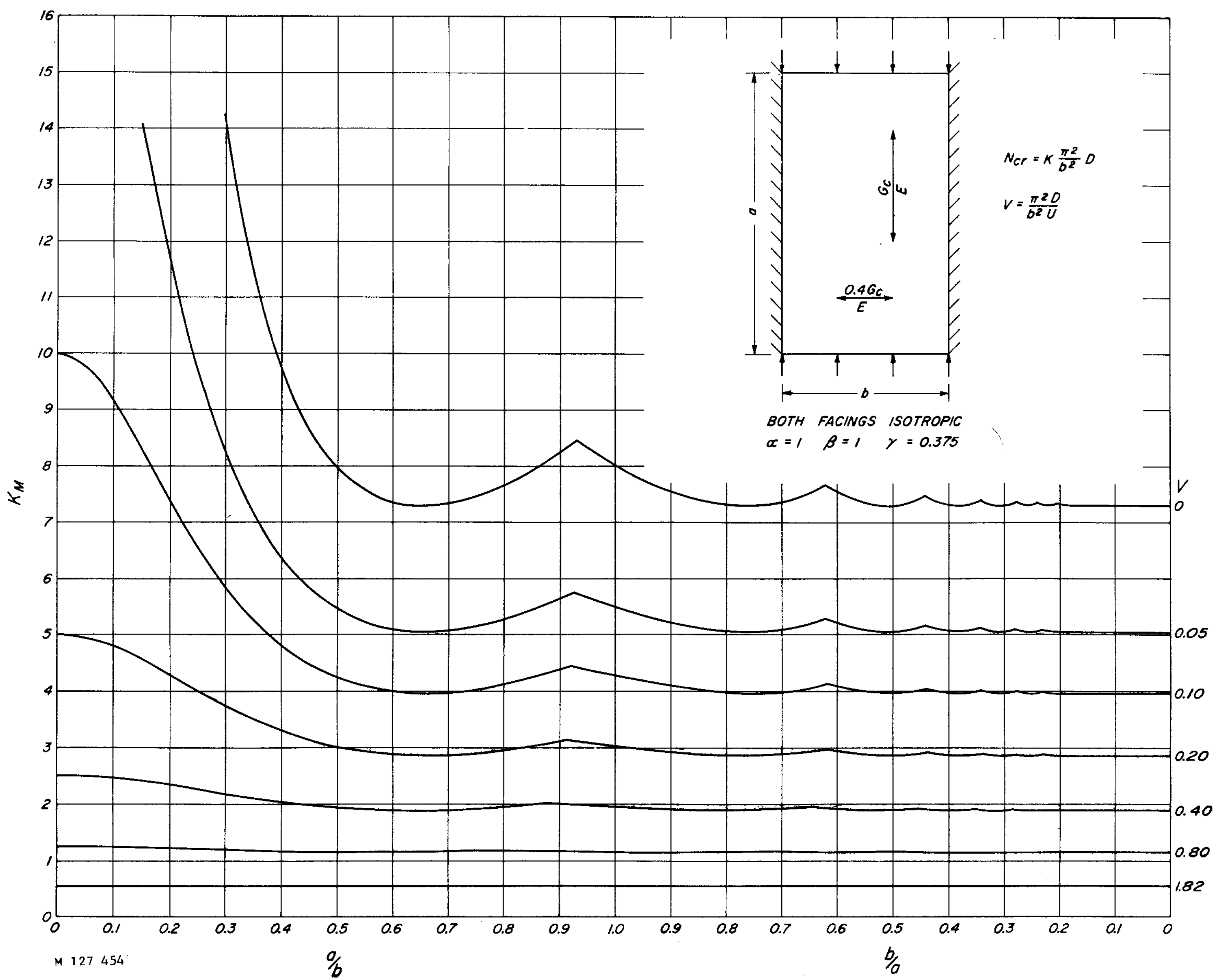


Figure 35.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

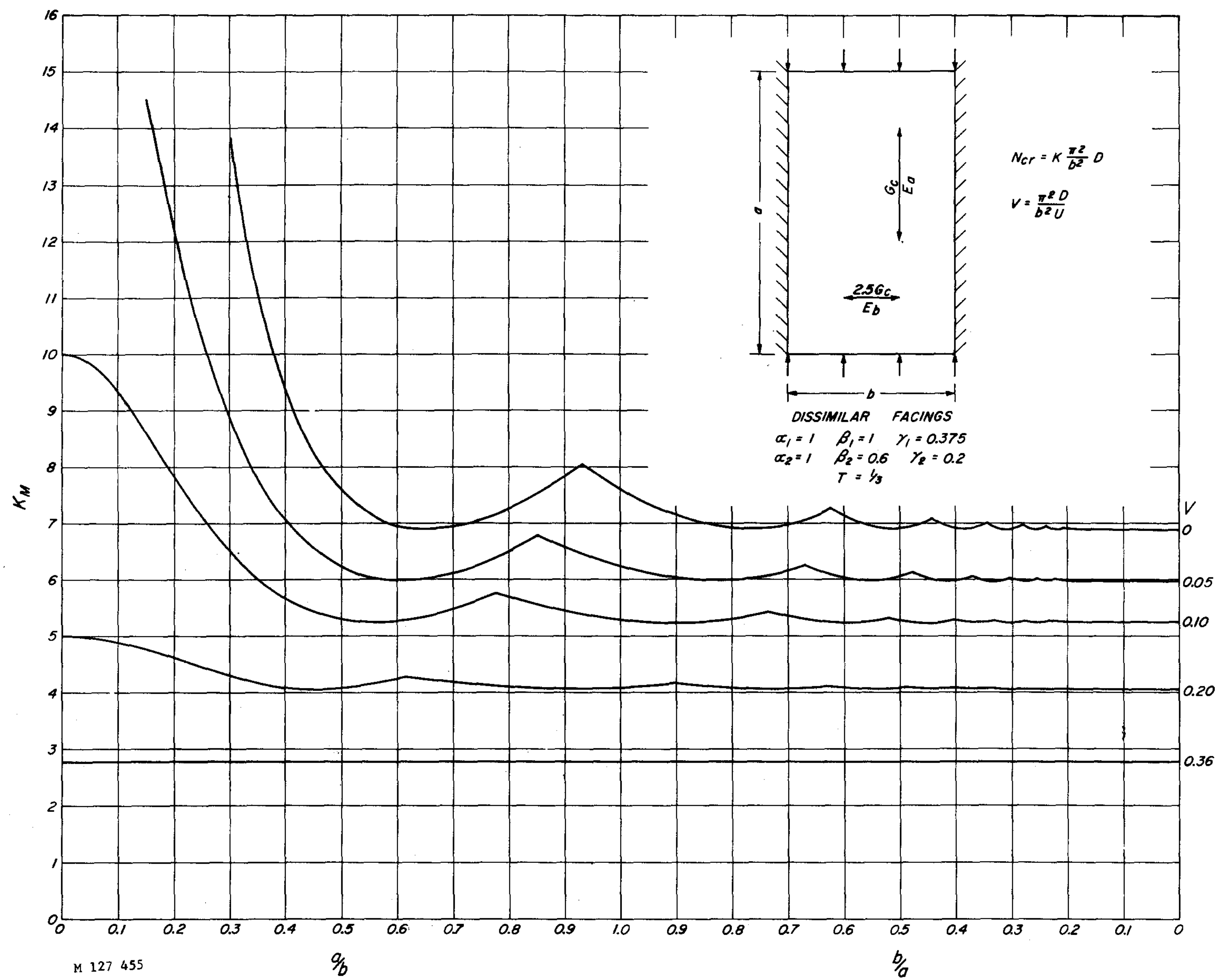


Figure 36.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

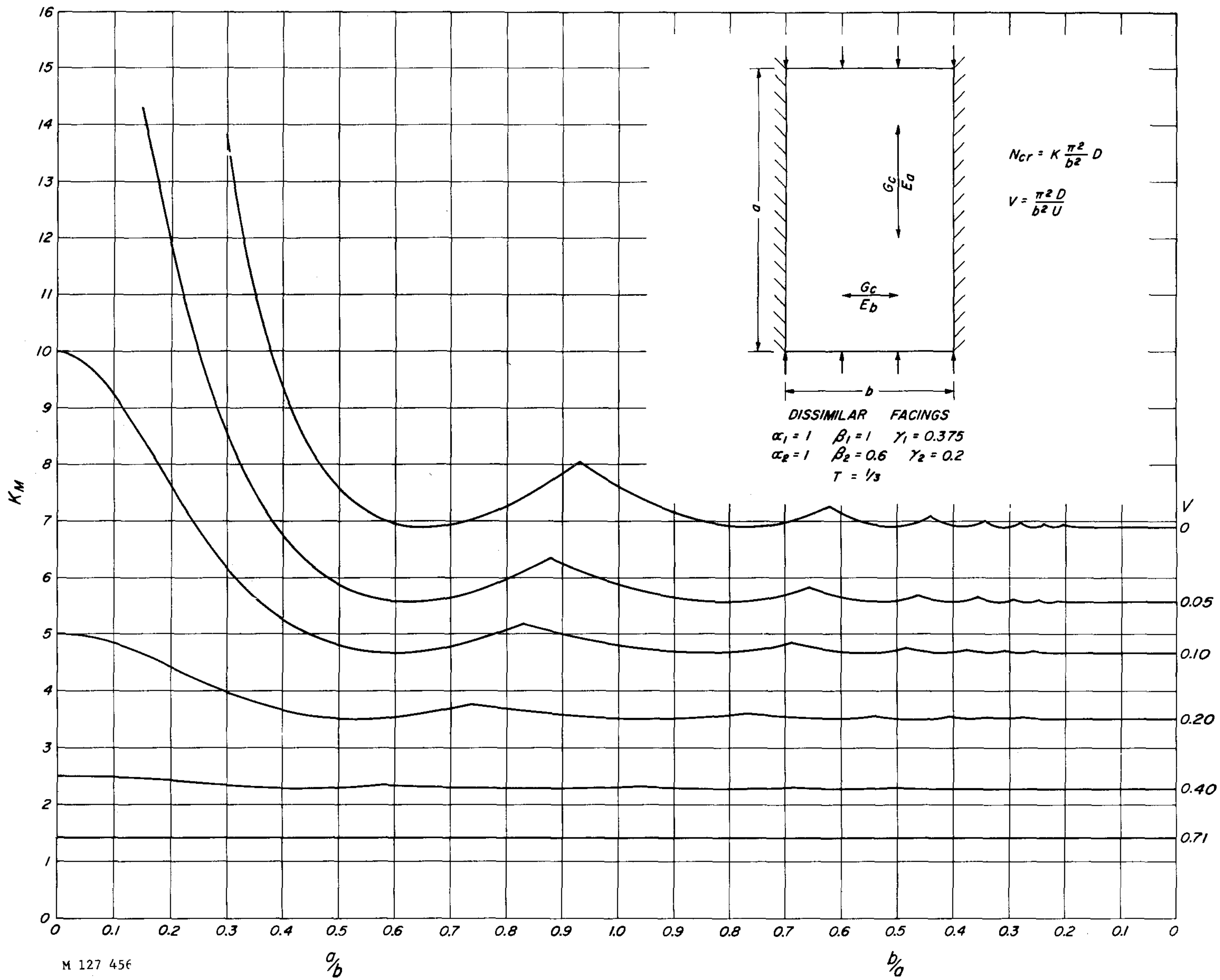
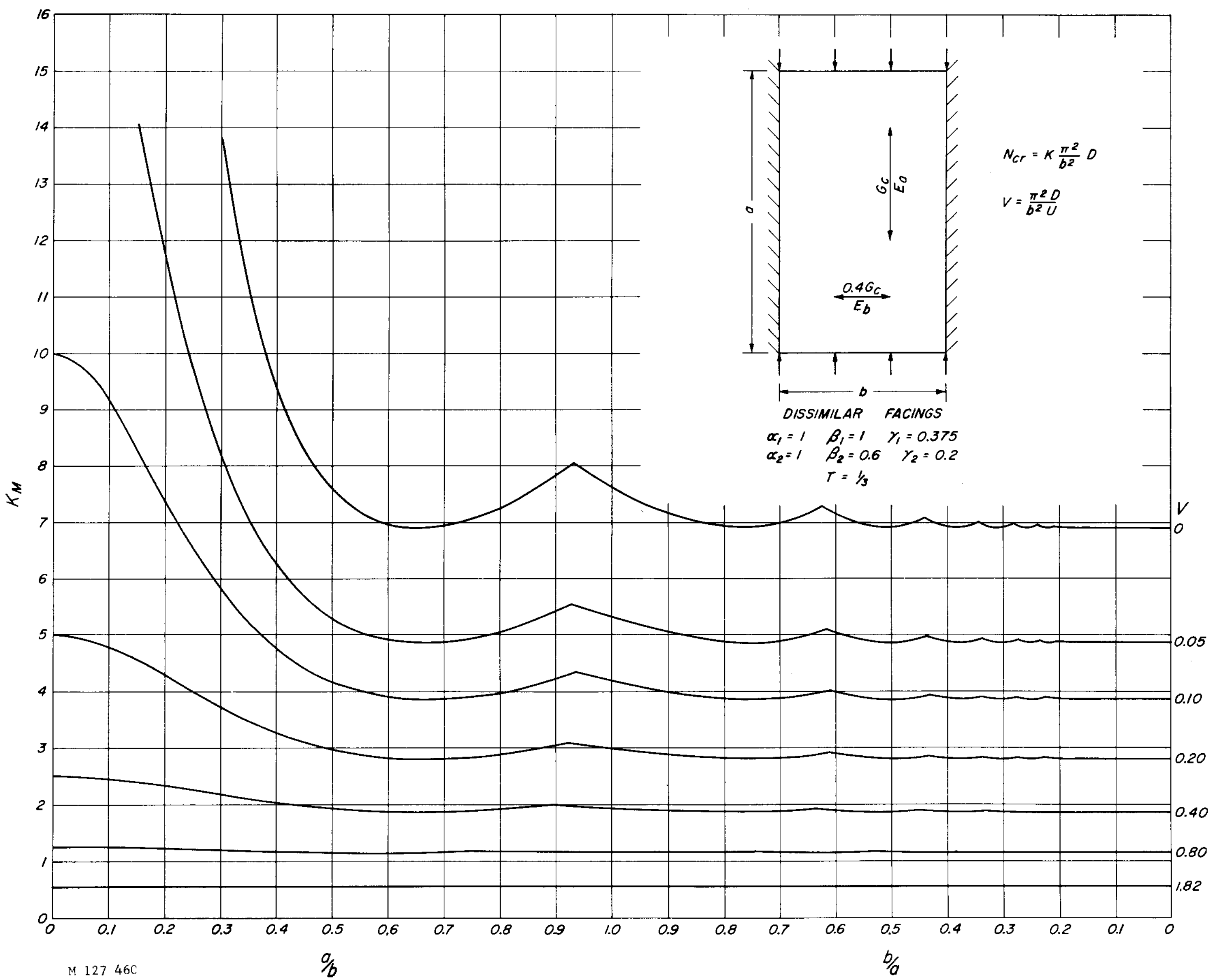
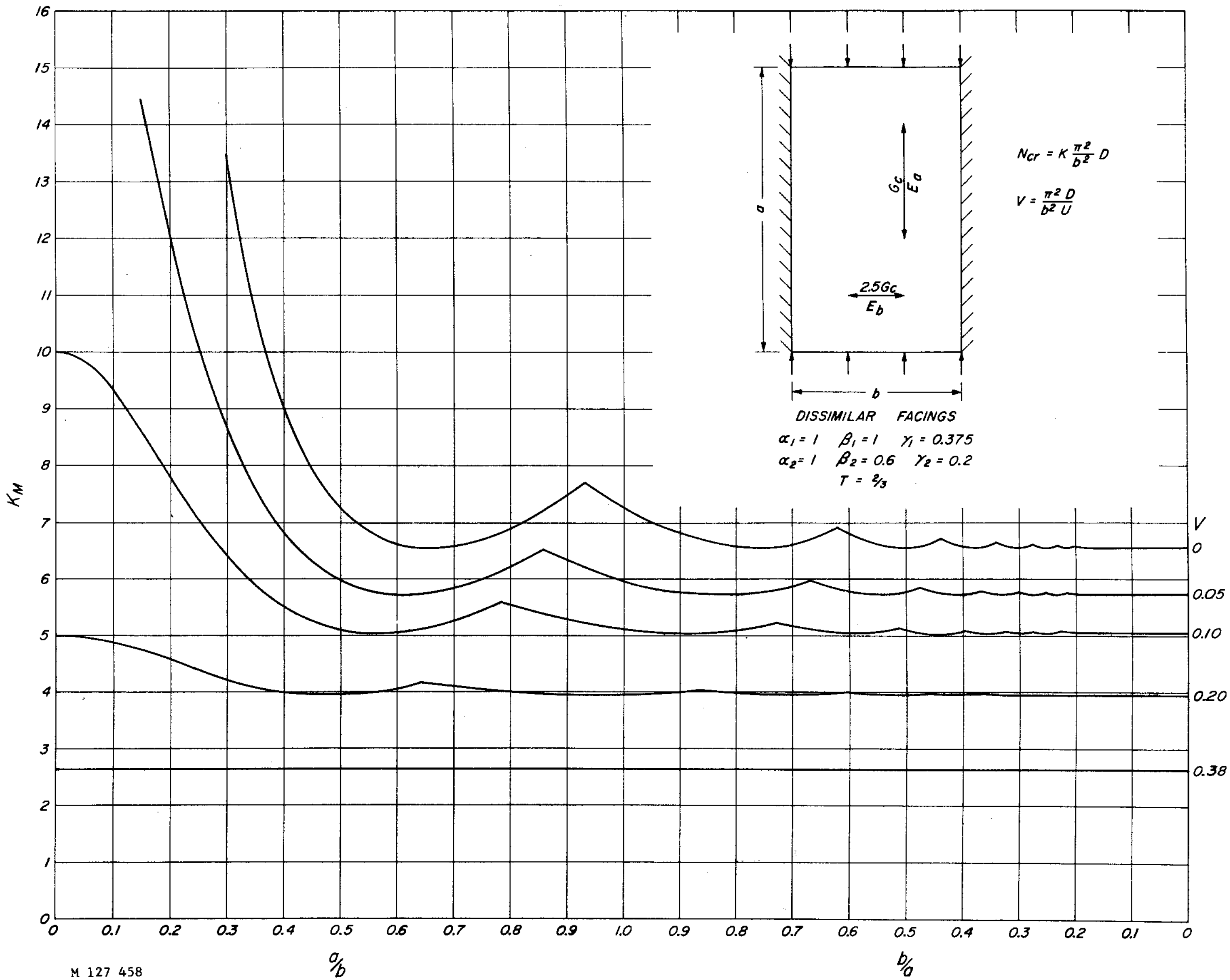


Figure 37.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 46C

Figure 38.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 458

Figure 39.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

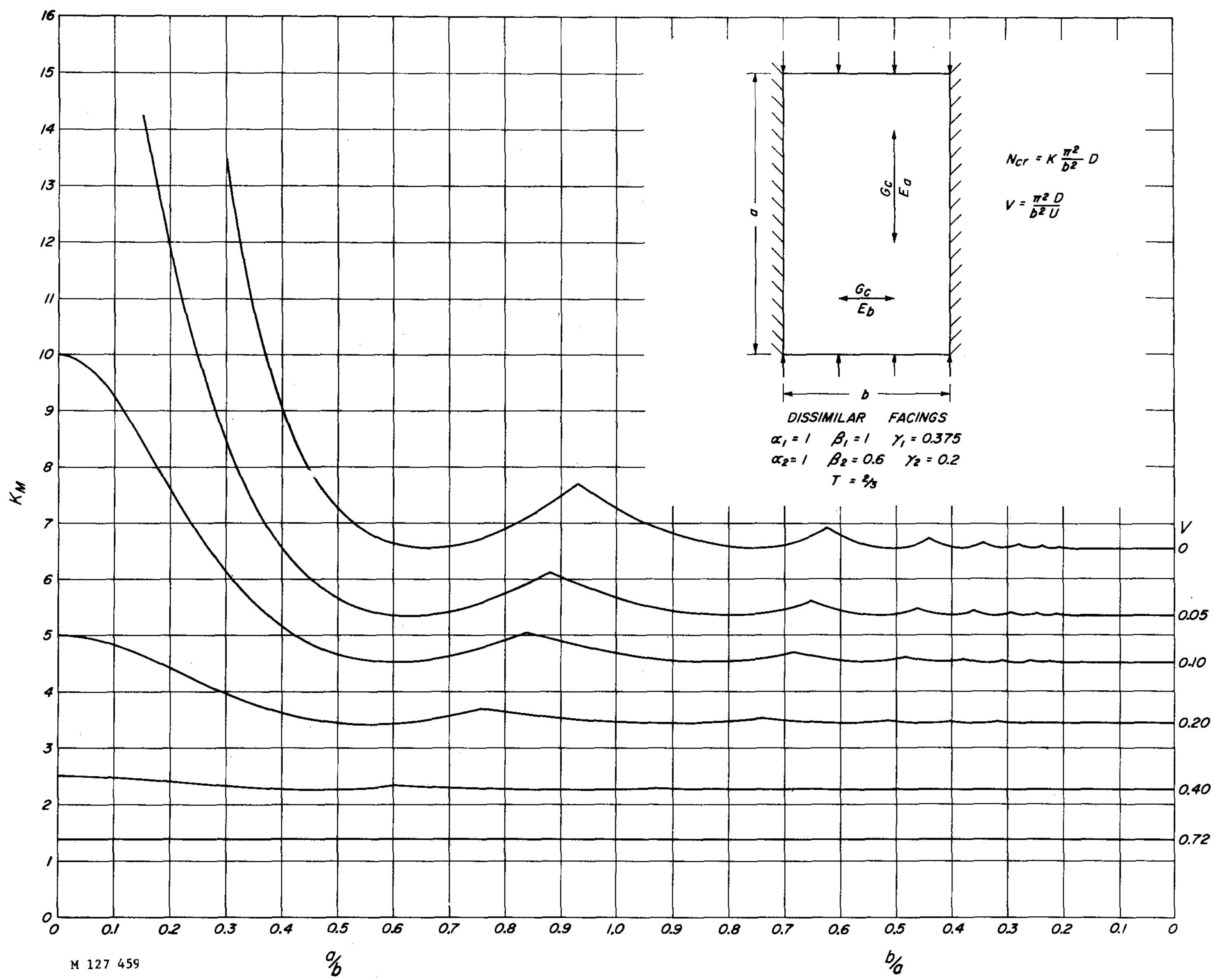


Figure 40.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

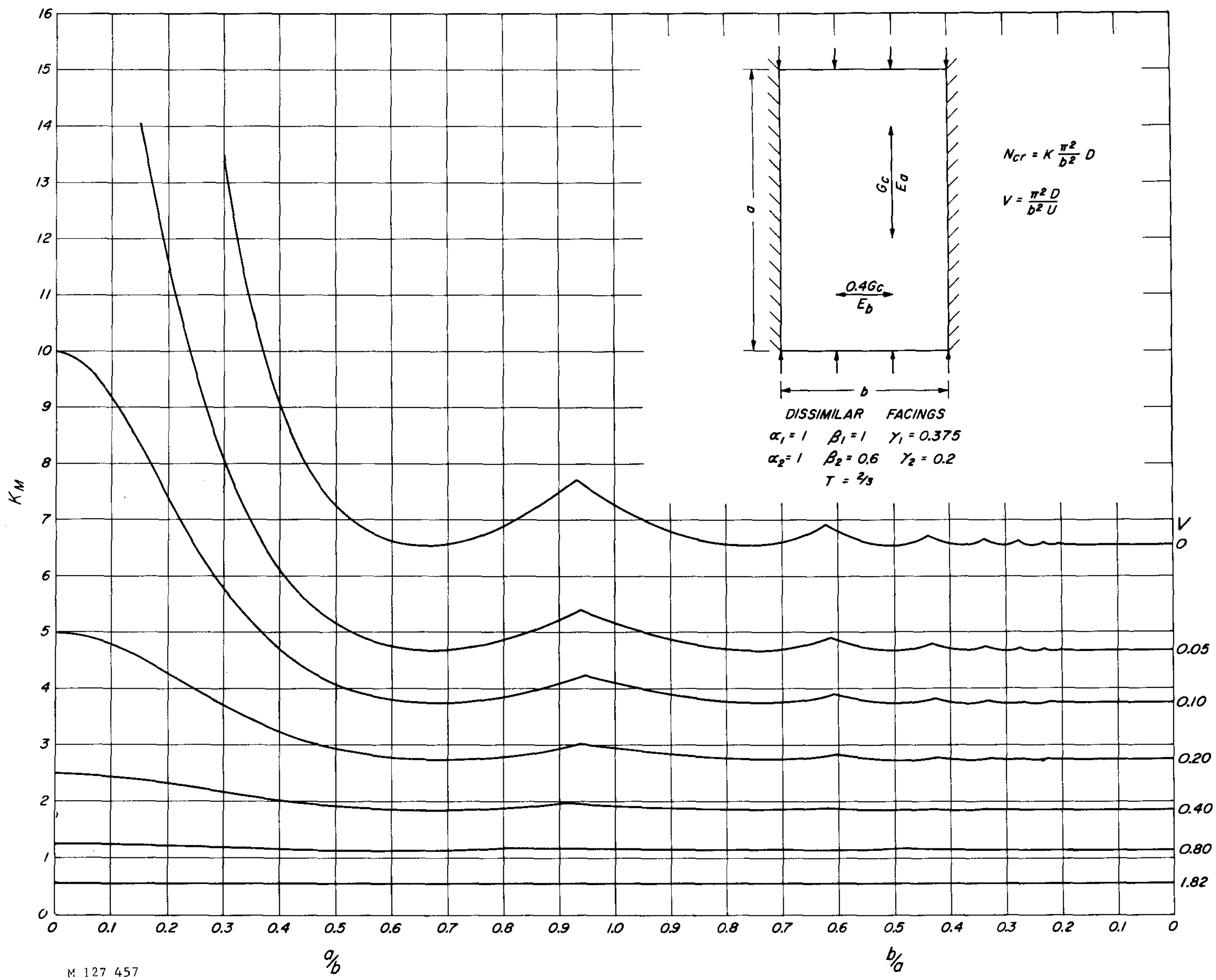


Figure 41.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

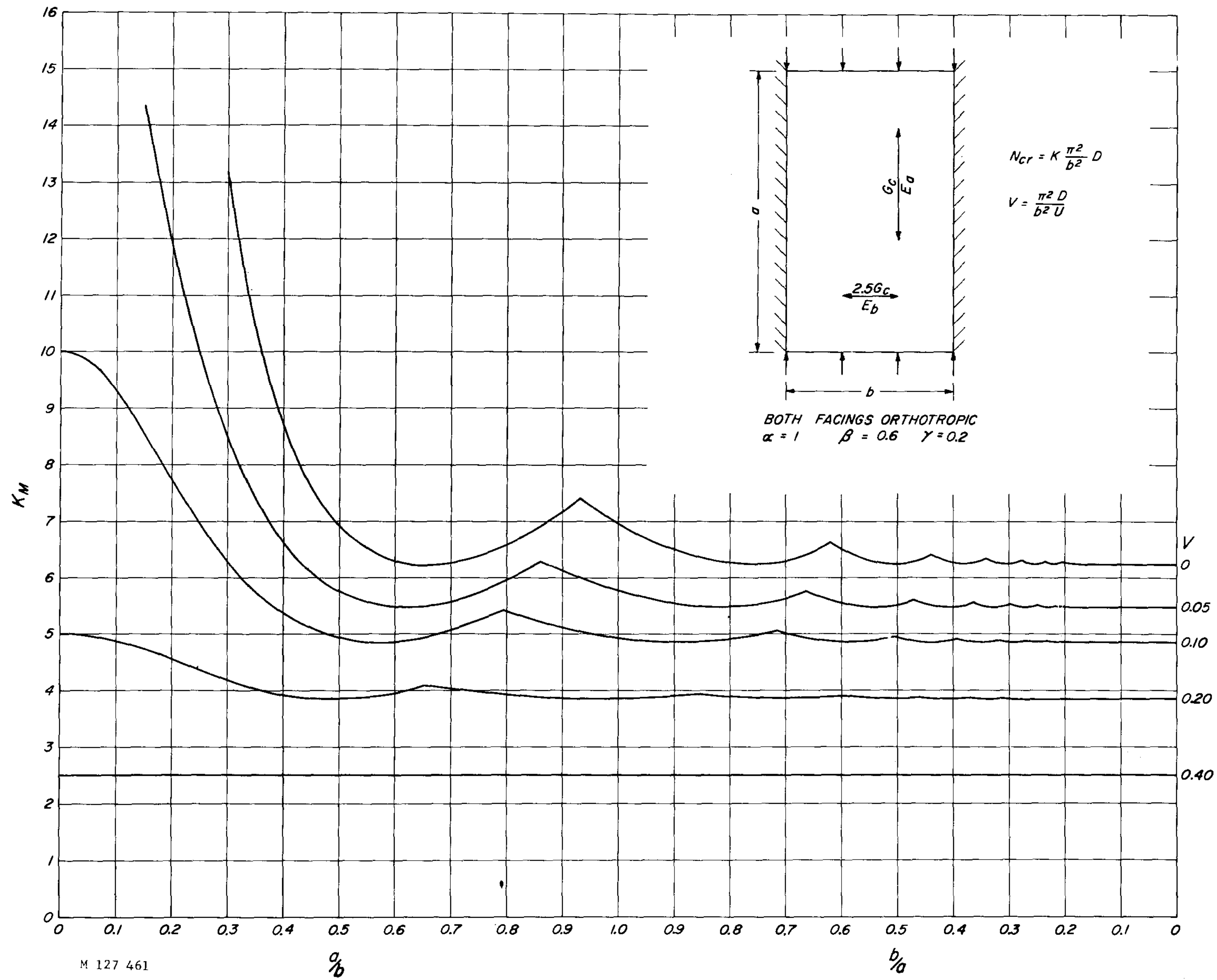
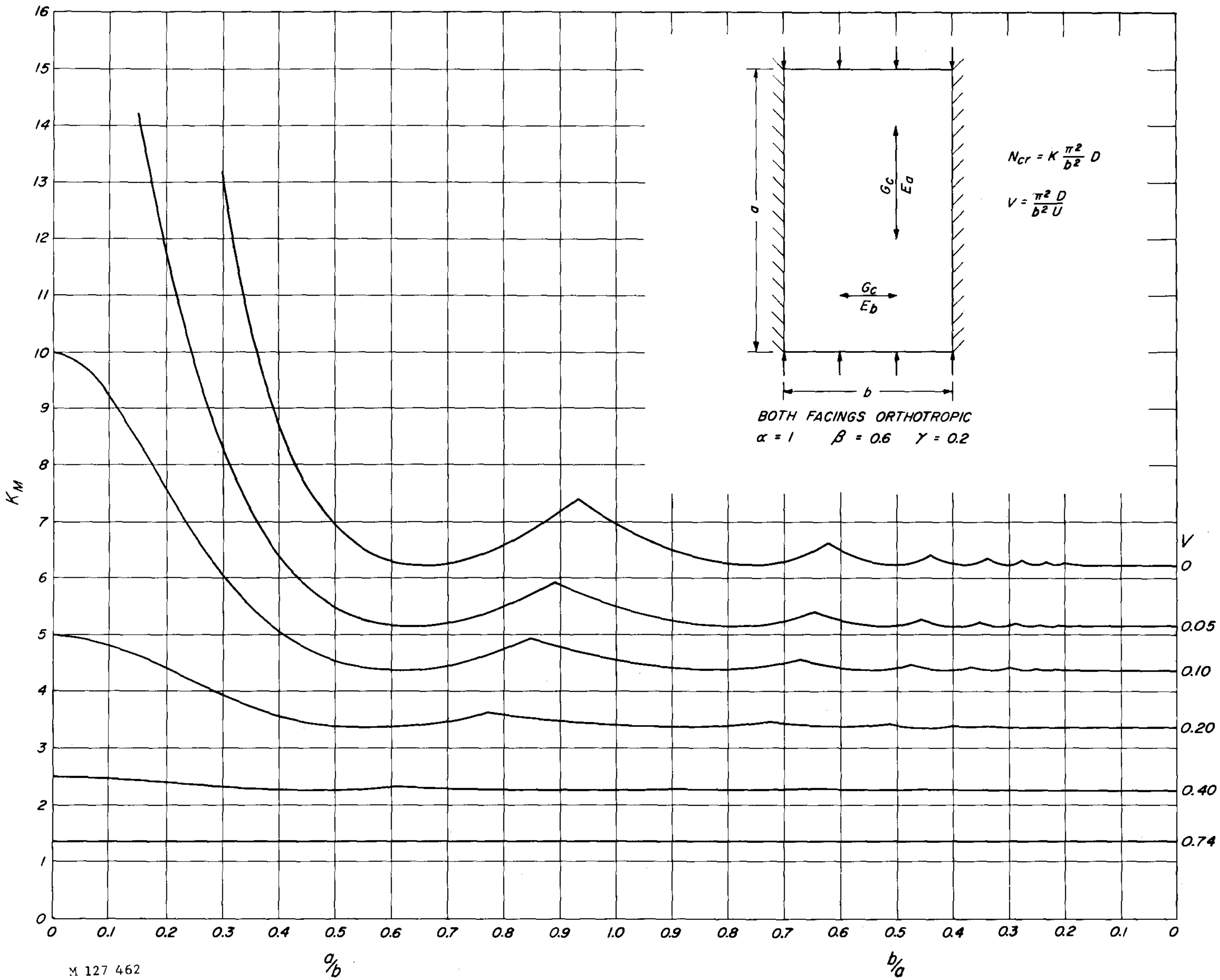
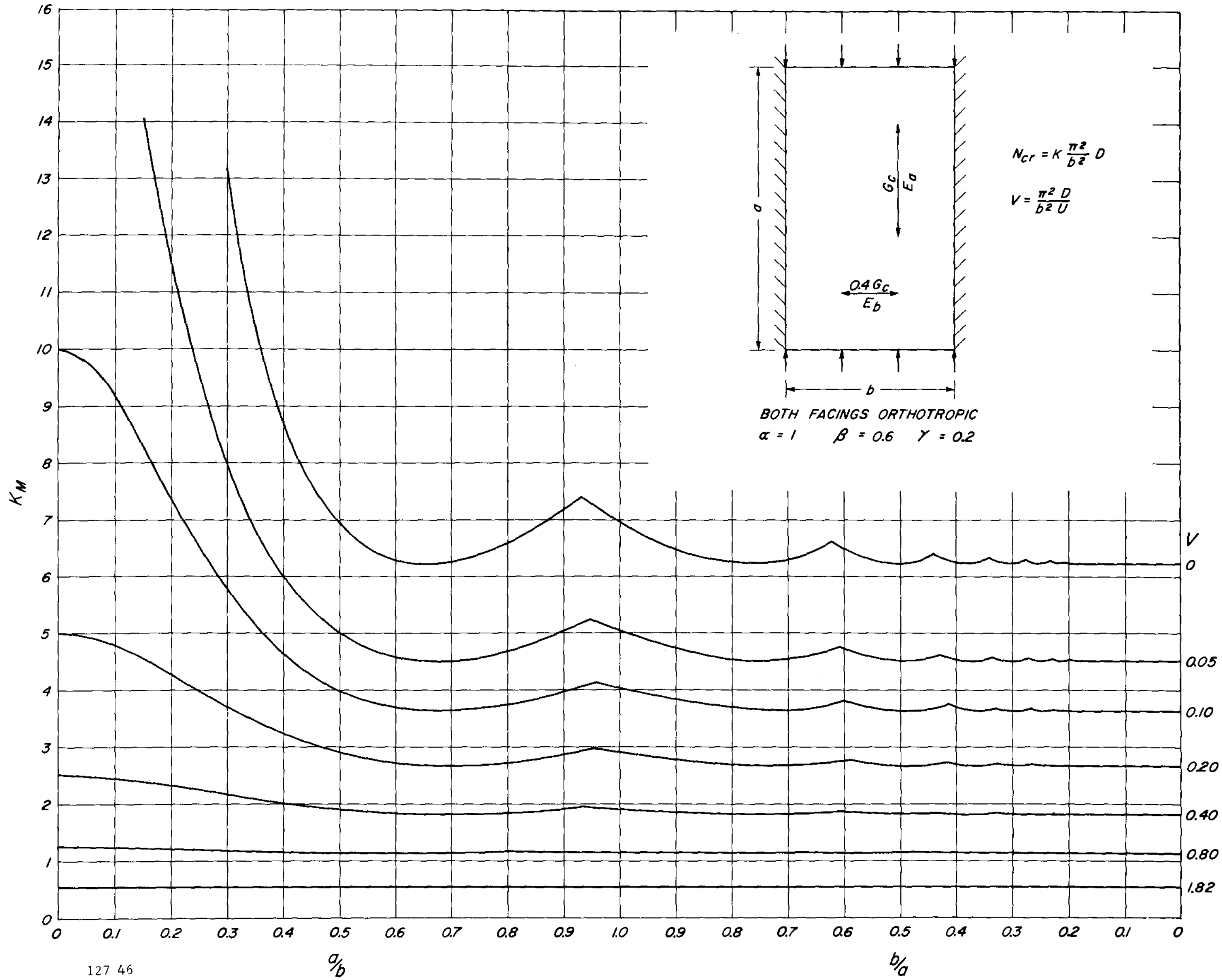


Figure 42.--Buckling coefficients for sandwich panels in edge compression Loaded edges simply supported, other edges clamped.



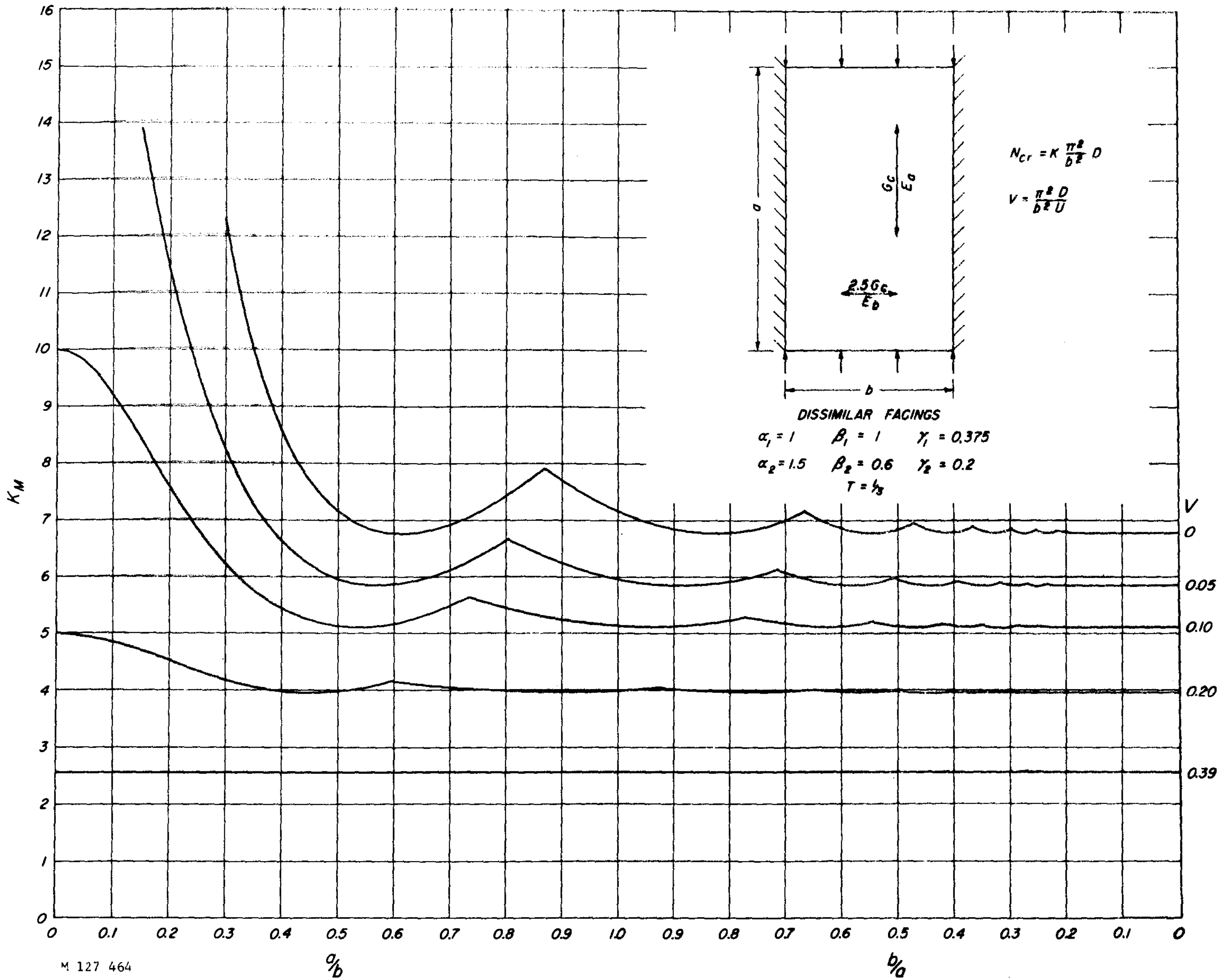
M 127 462

Figure 43.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



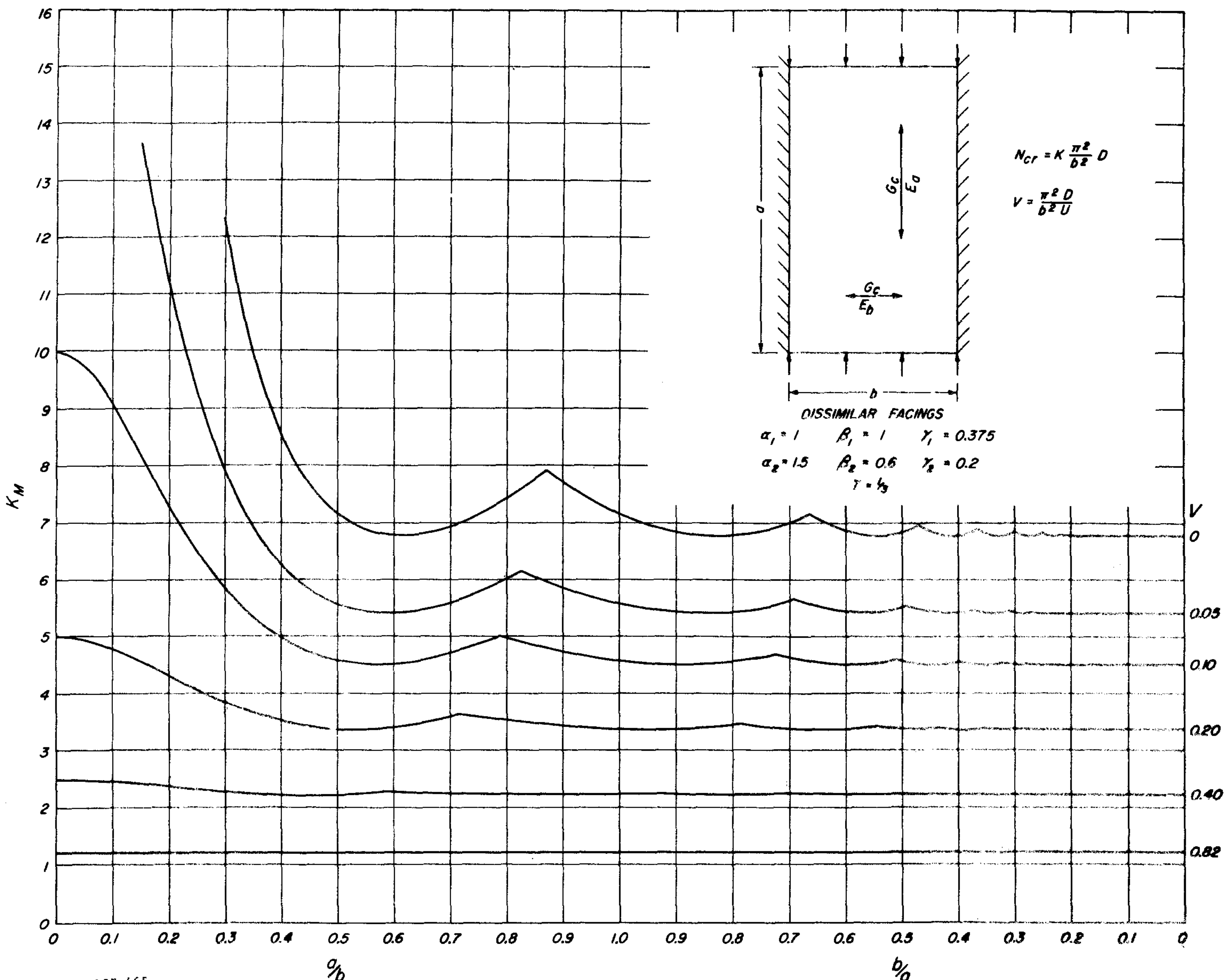
127 46

Figure 44.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 464

Figure 45.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 465

Figure 46.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

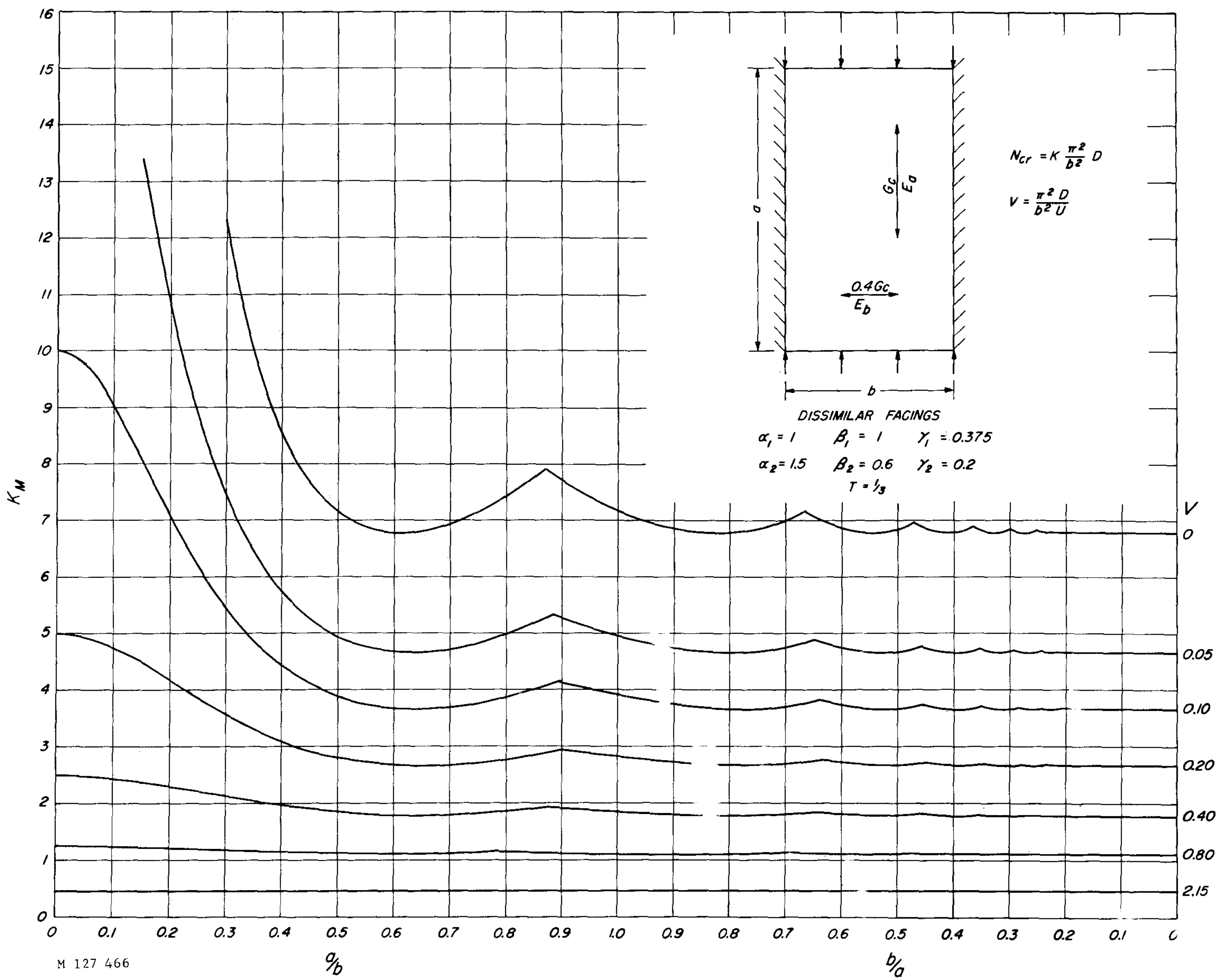


Figure 47.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

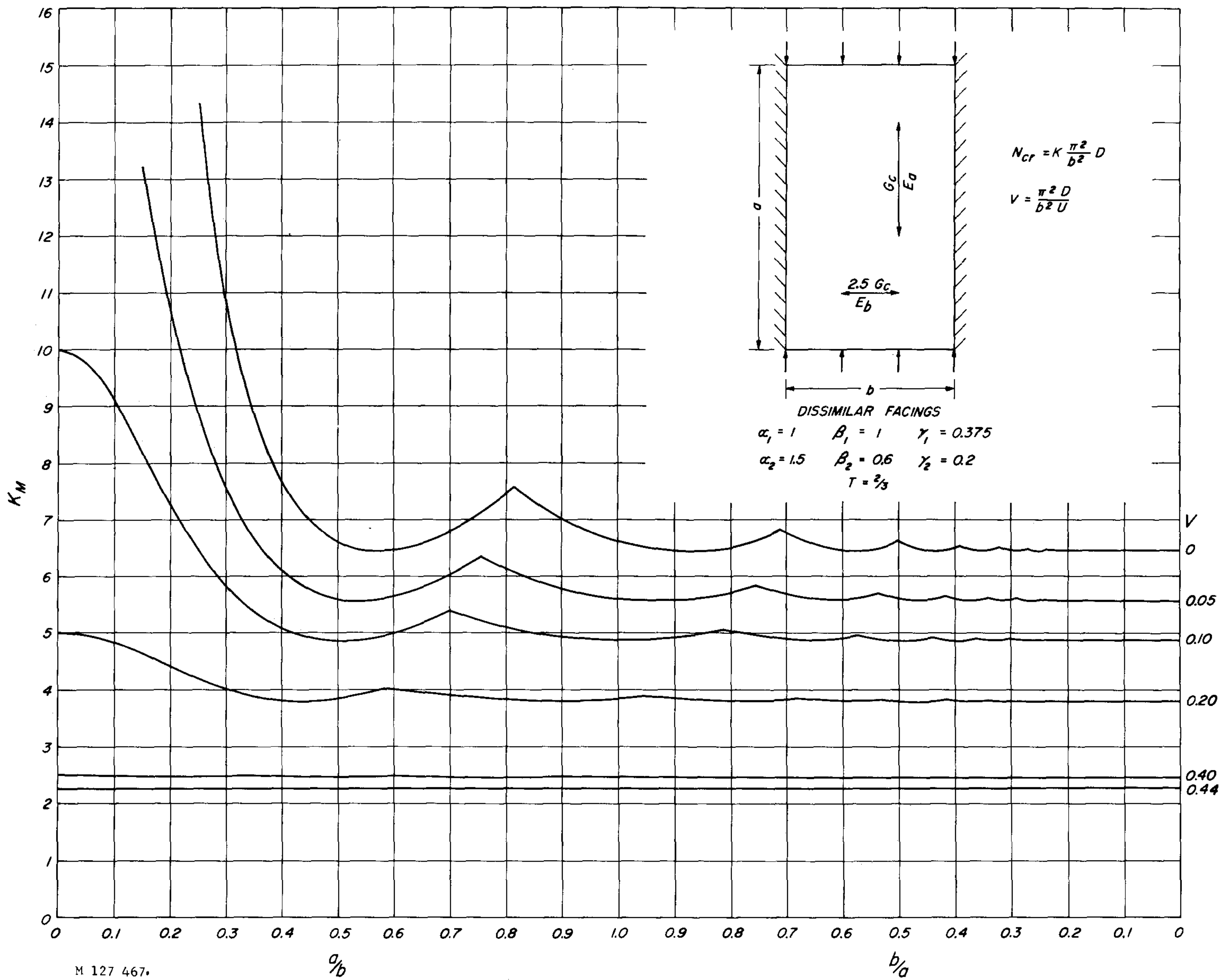
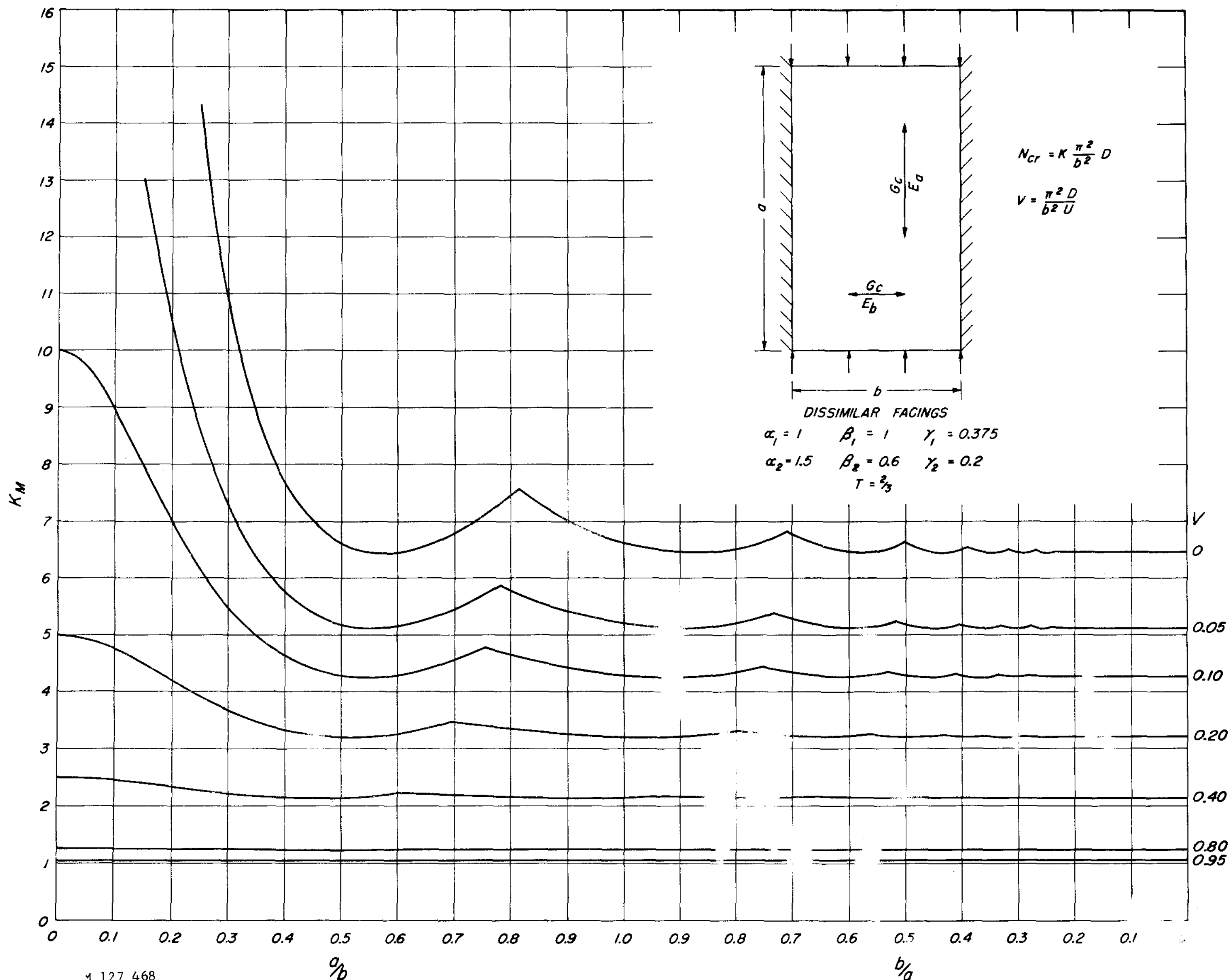
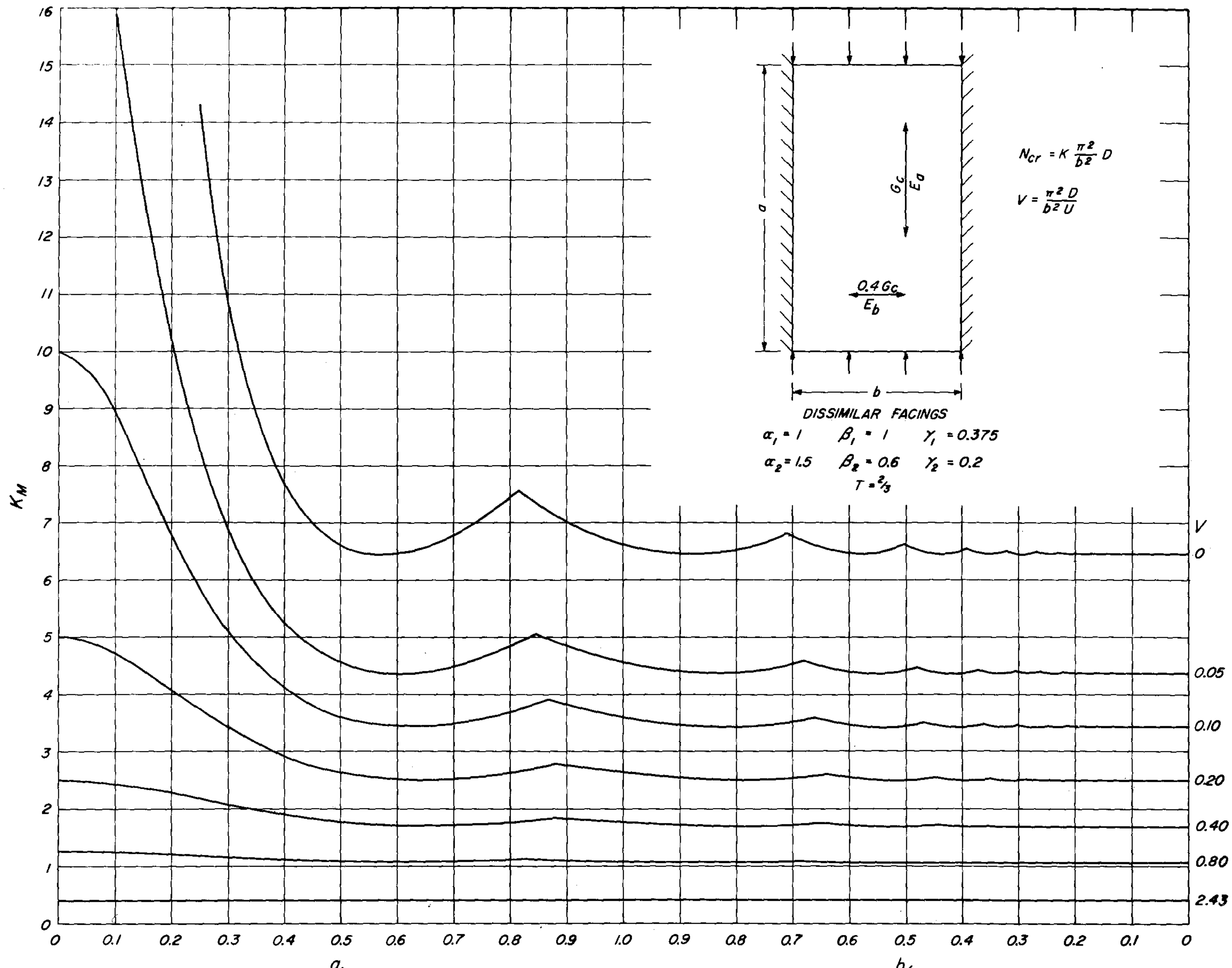


Figure 48.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



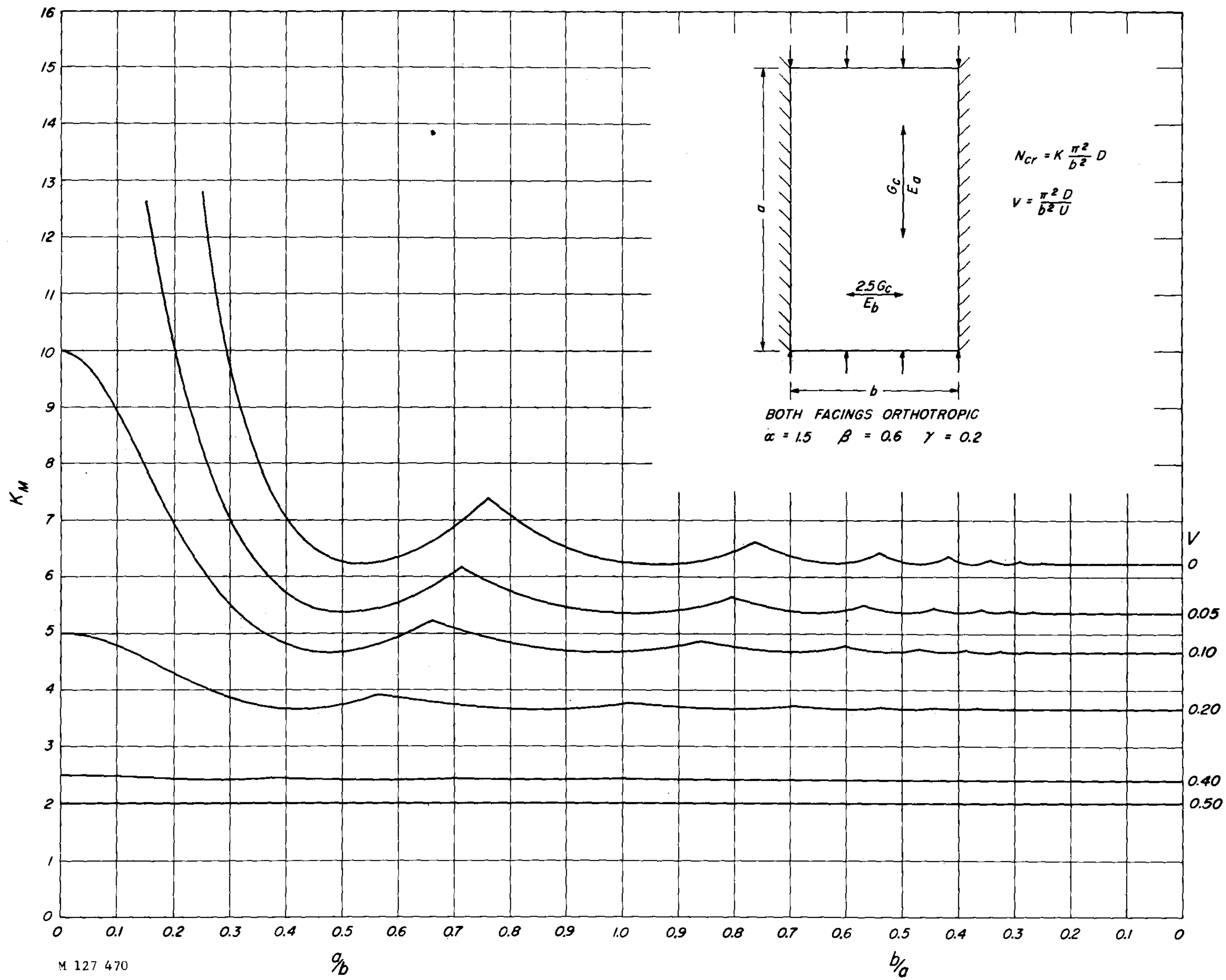
M 127 468

Figure 49.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 469

Figure 50.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 470

Figure 51.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

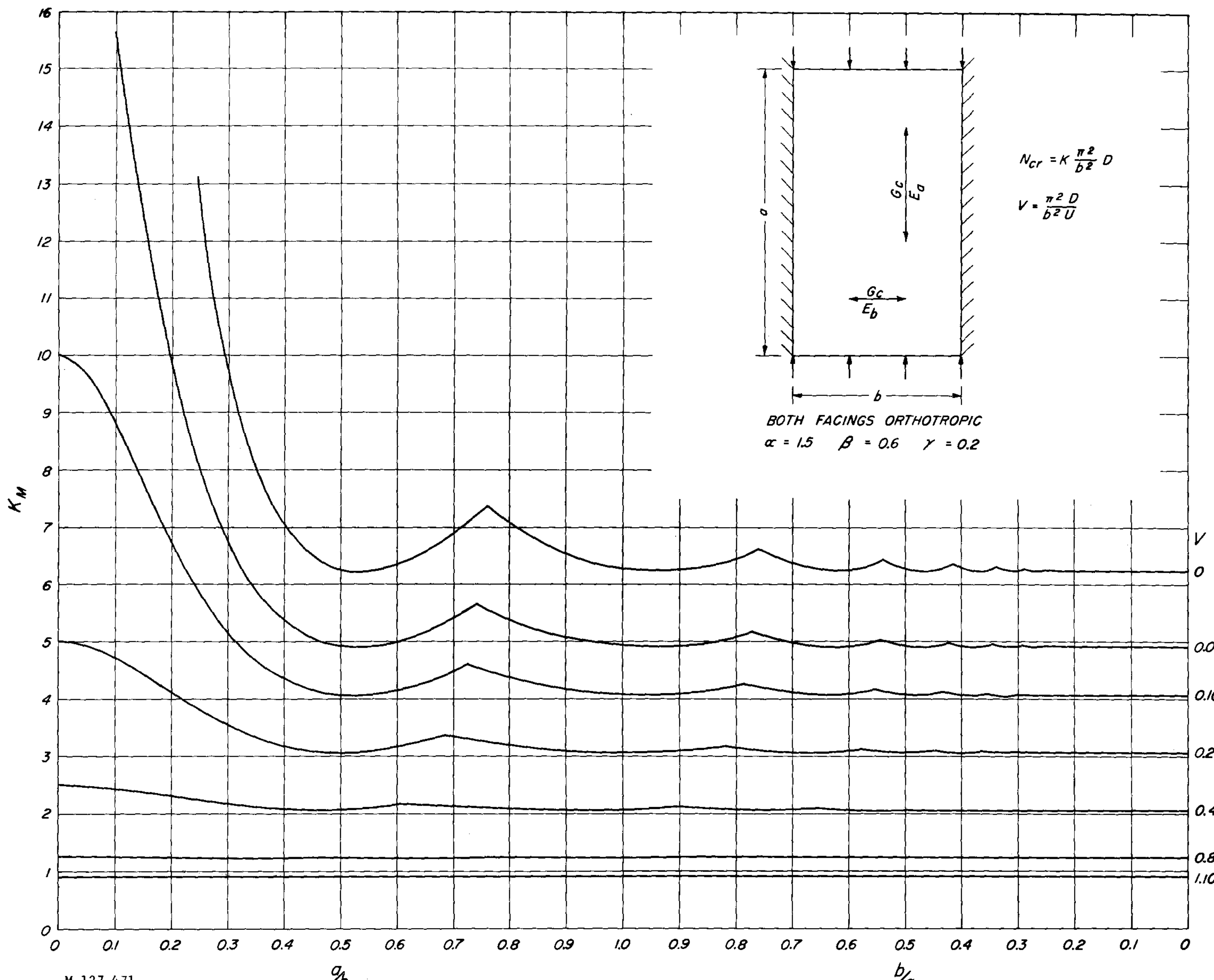
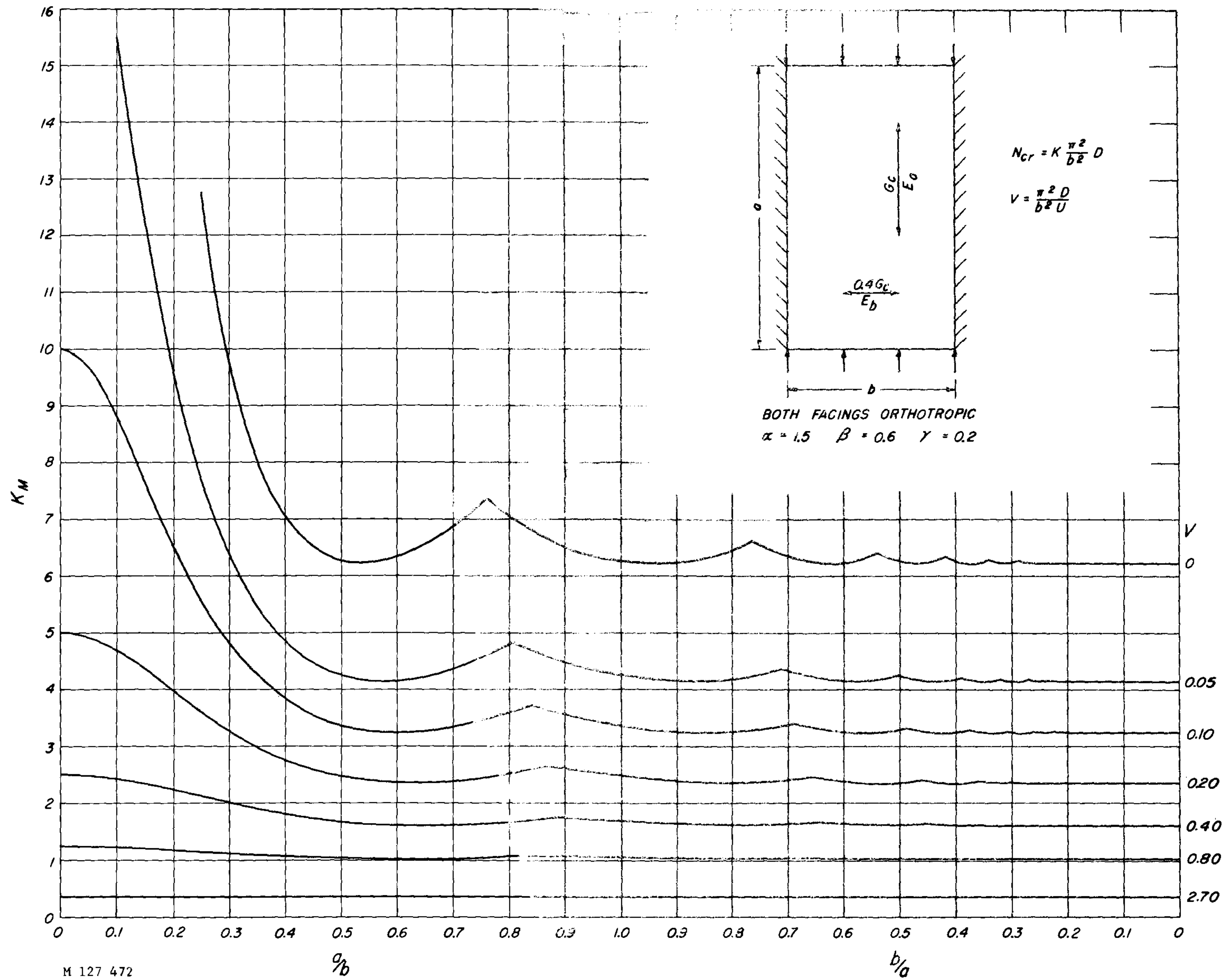


Figure 52.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



M 127 472

Figure 53.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.

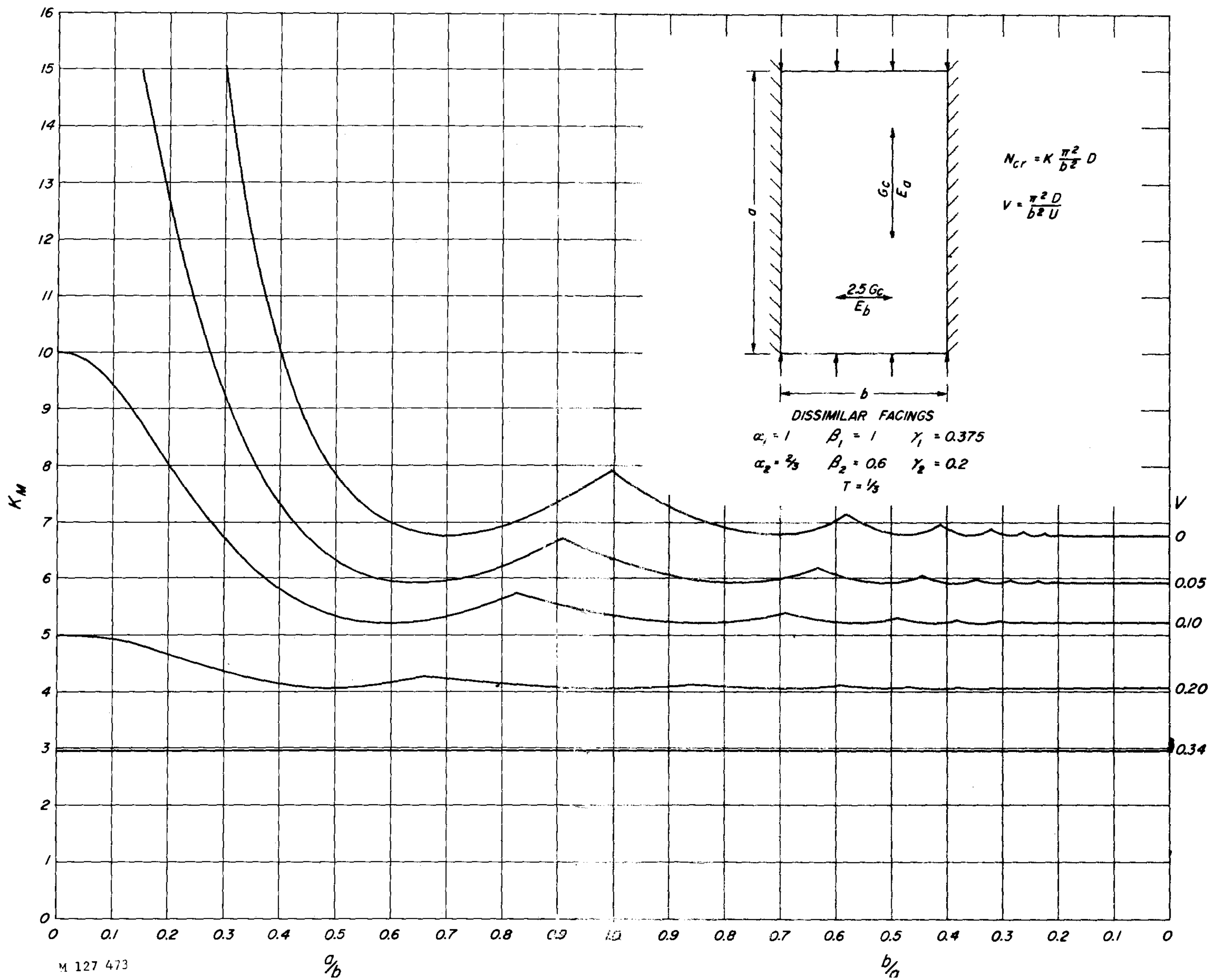
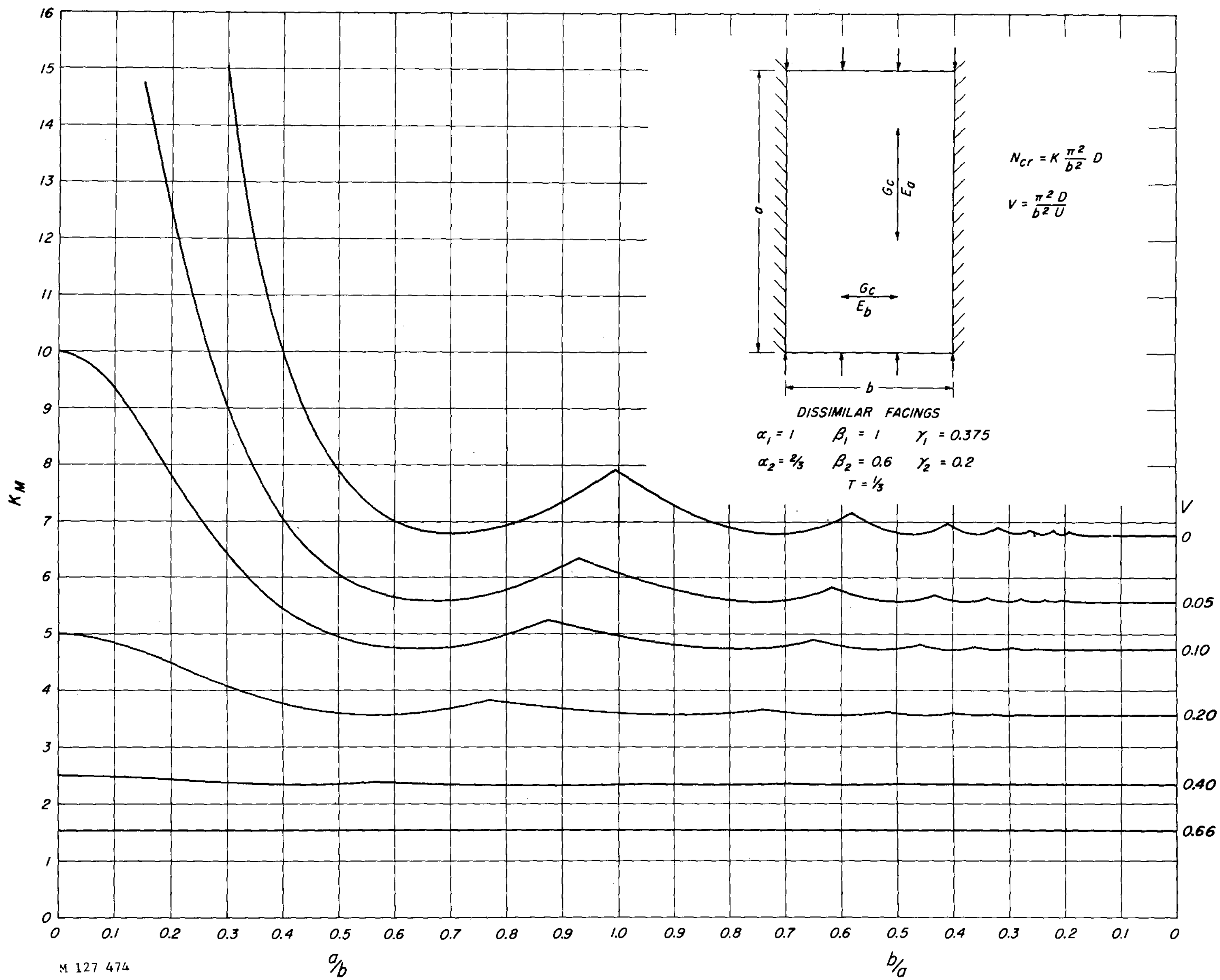
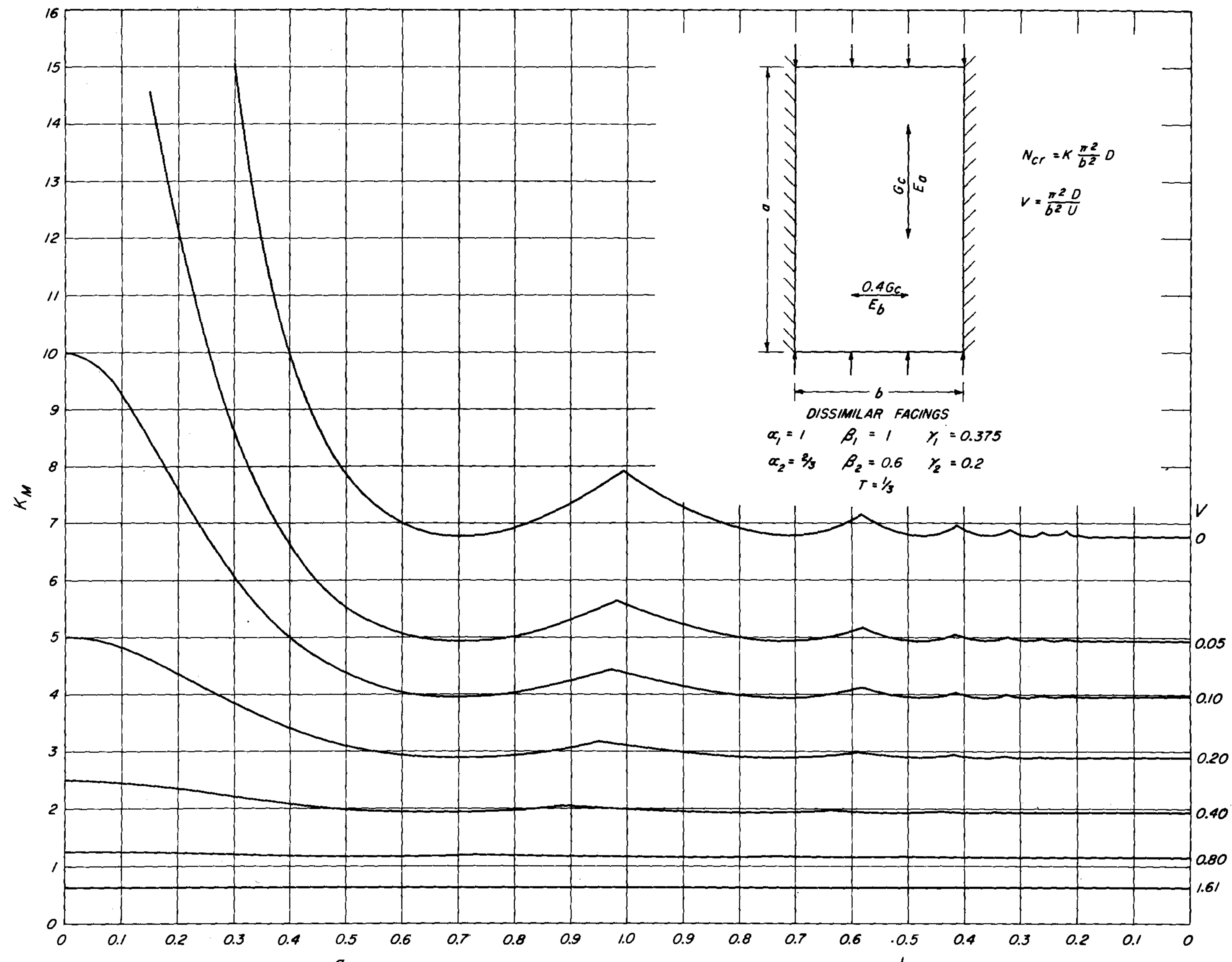


Figure 54.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



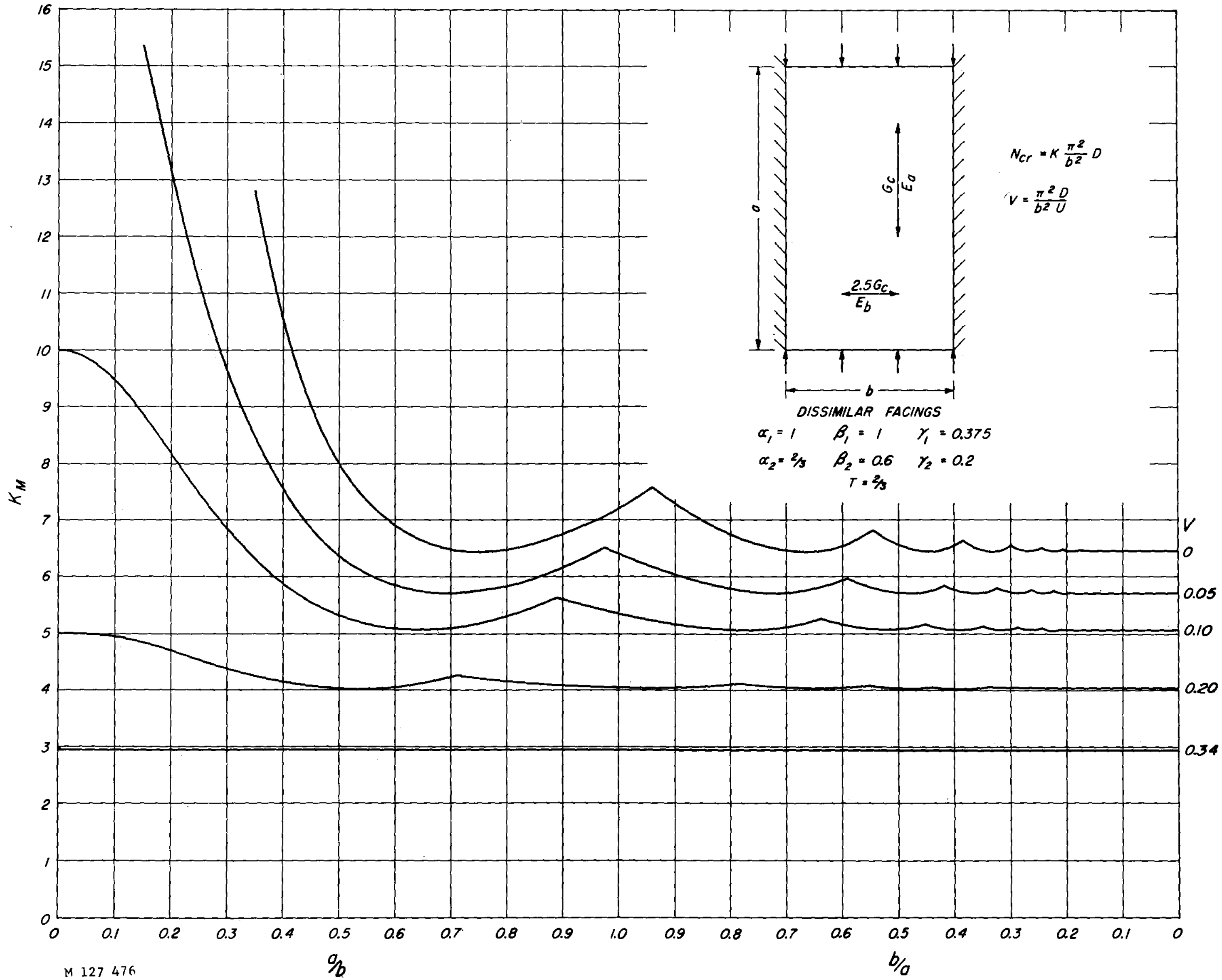
M 127 474

Figure 55.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



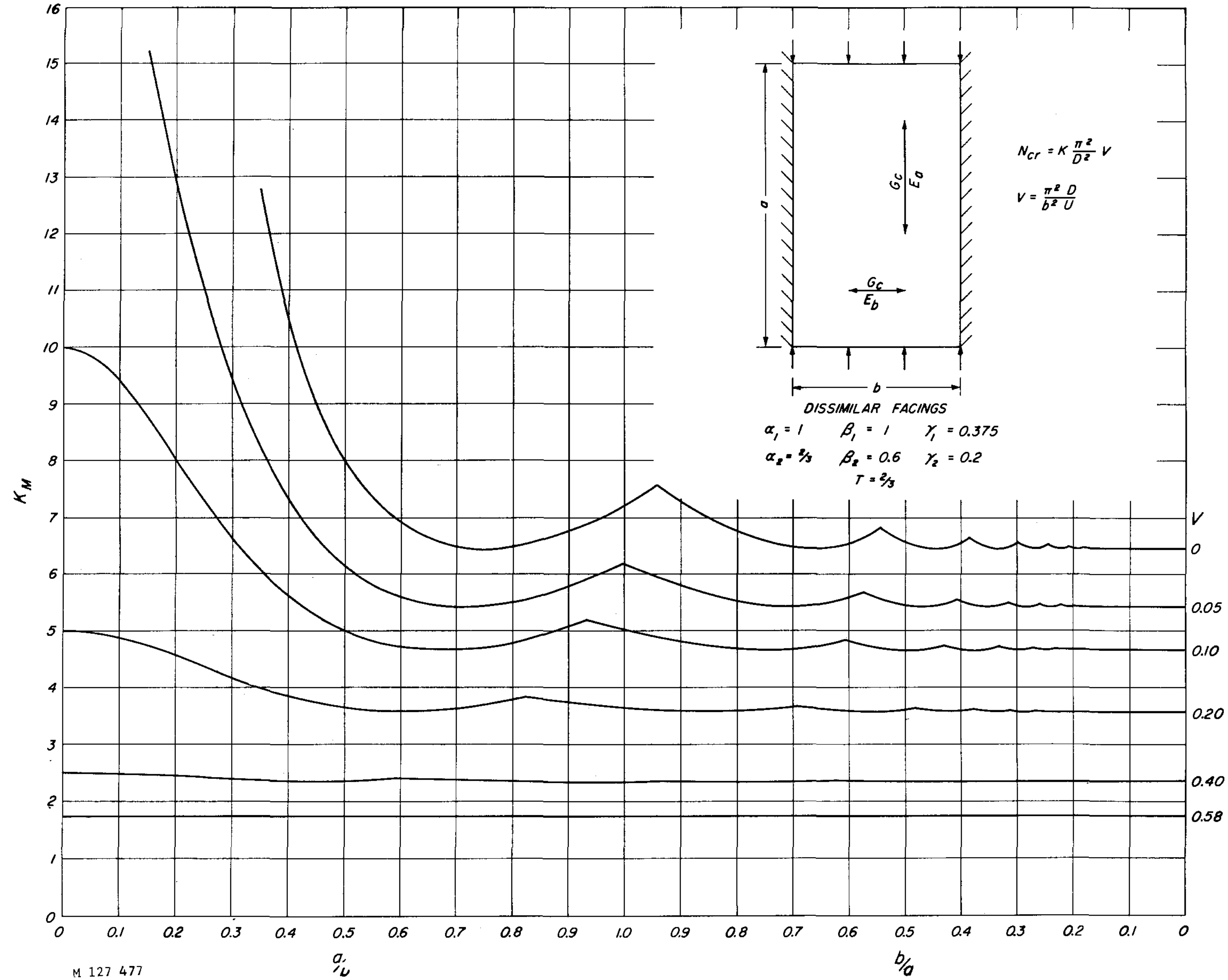
M 127 475

Figure 56.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



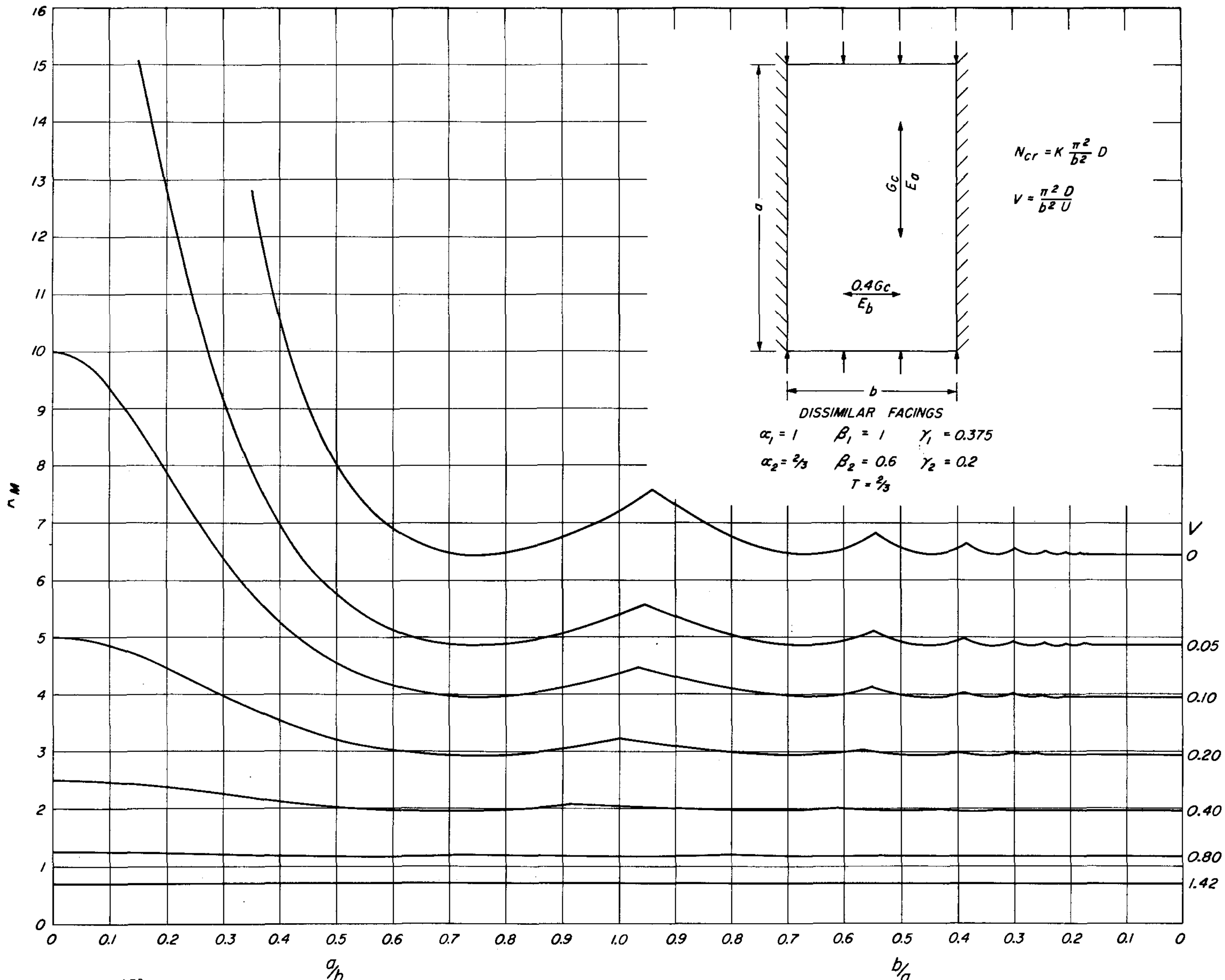
M 127 476

Figure 57.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



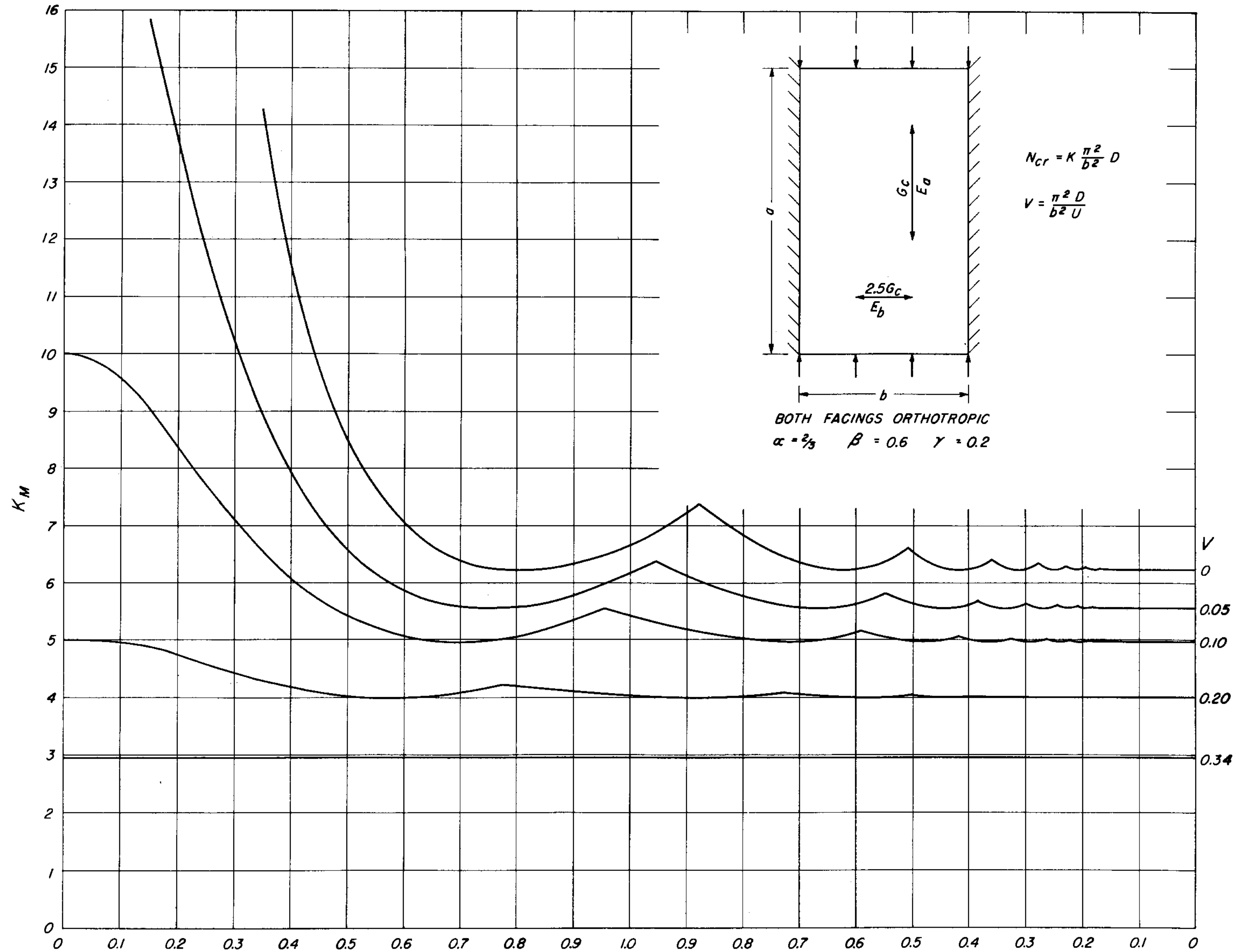
M 127 477

Figure 58.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



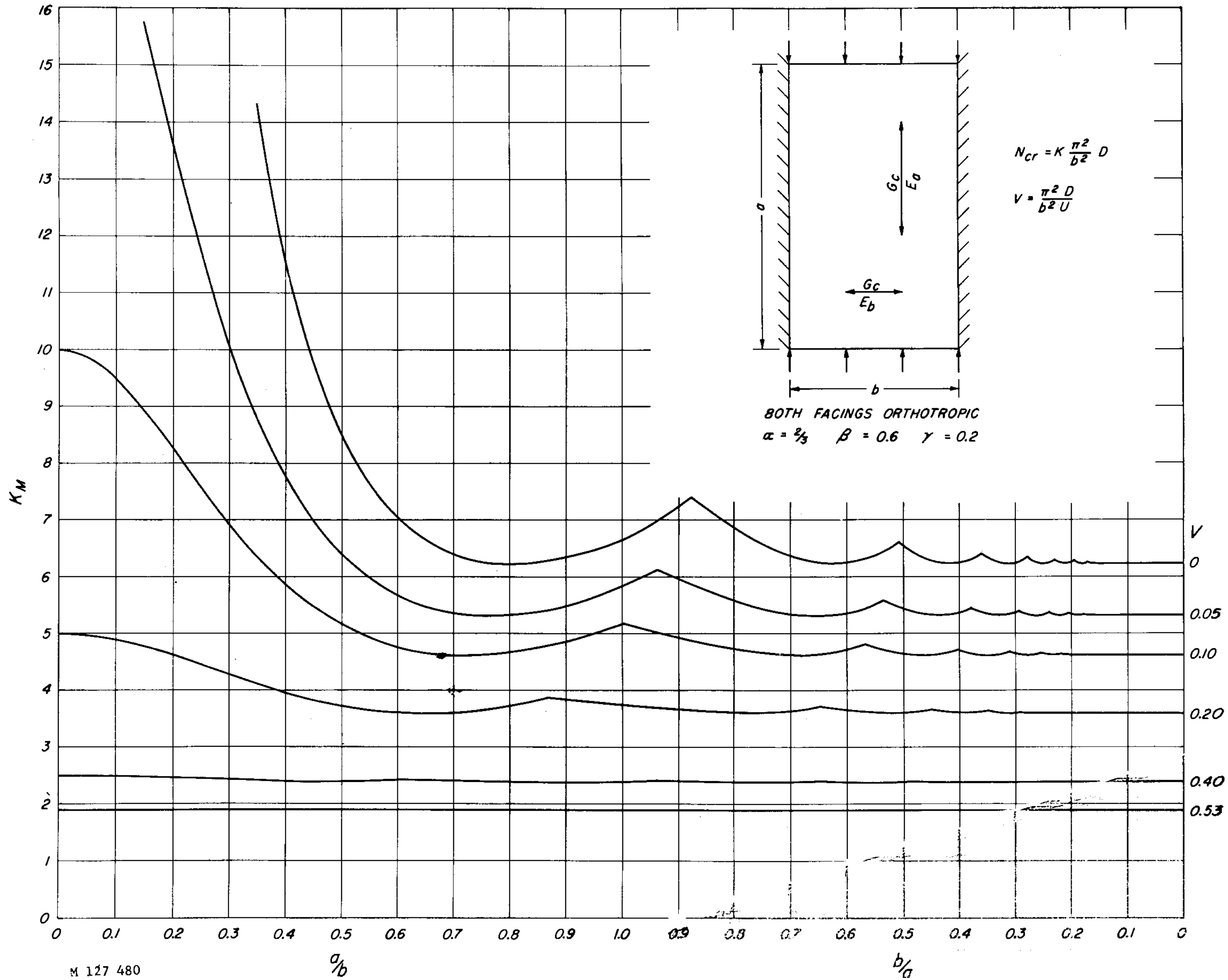
M 127 478

Figure 59.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported. other edges clamped.



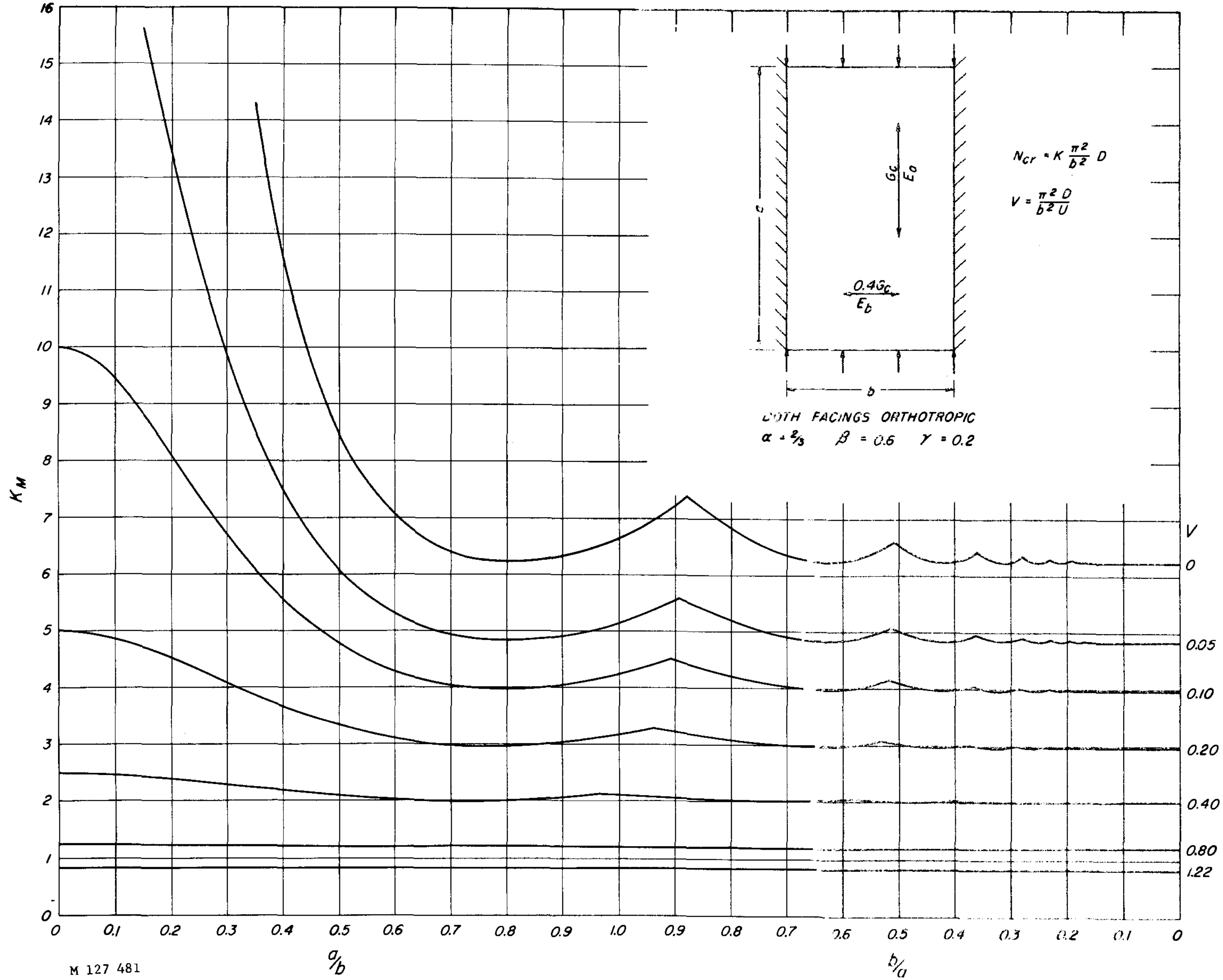
M 127 479

Figure 60.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



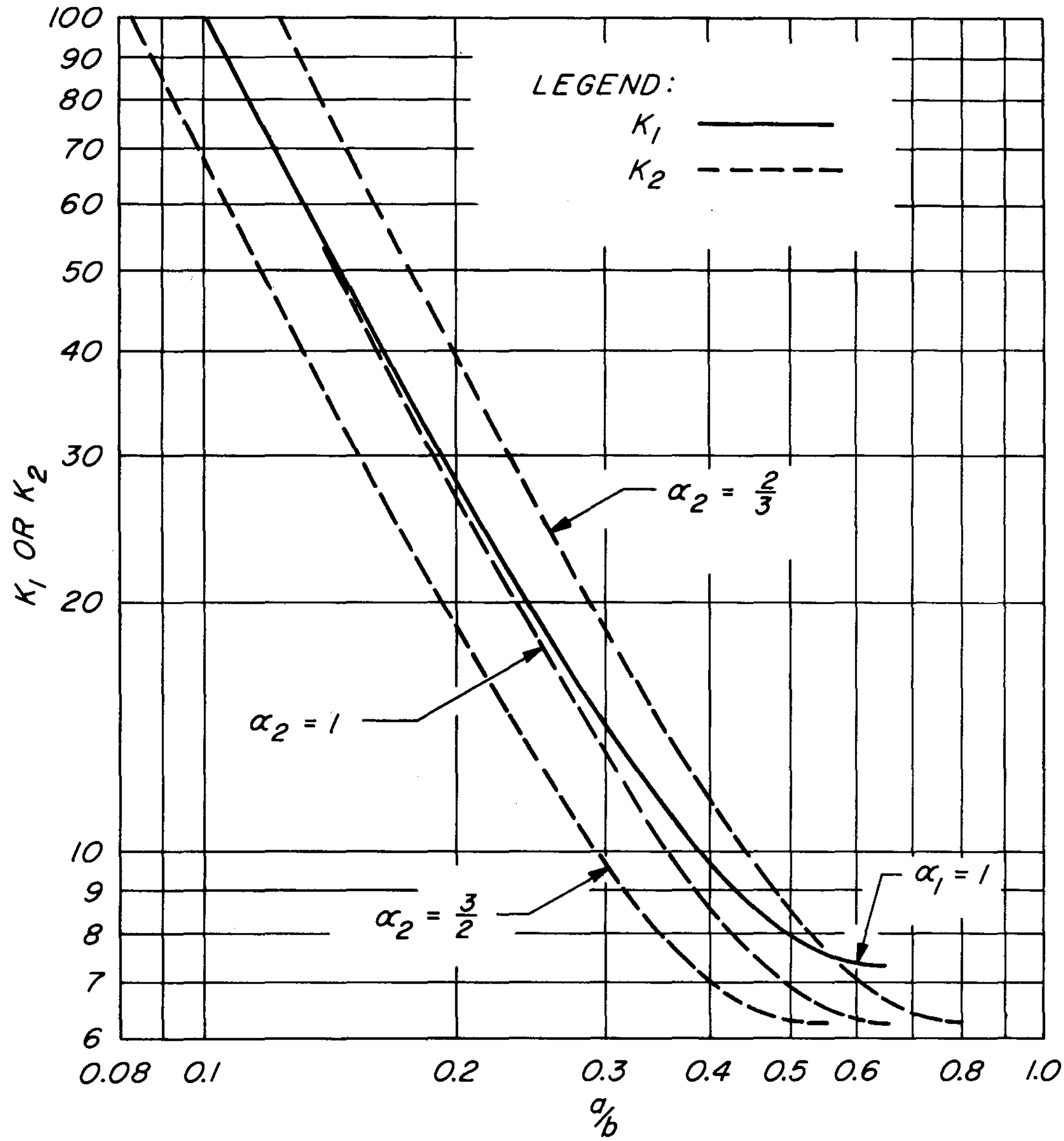
M 127 480

Figure 61.--Buckling coefficients for sandwich panels in edge compression. Loaded edges simply supported, other edges clamped.



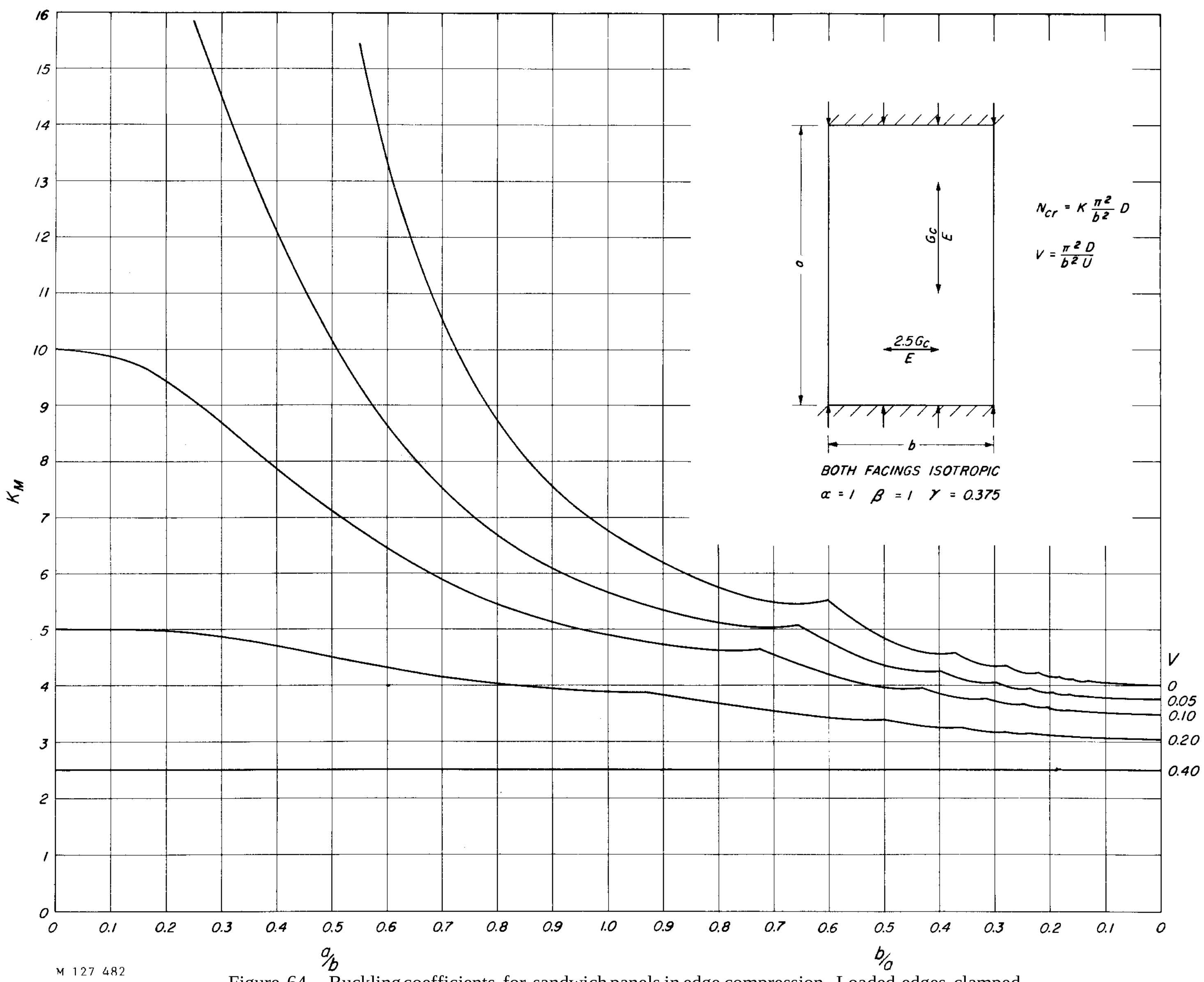
M 127 481

Figure 62.--Buckling coefficients for sandwich panels in edge compression. Loaded edge simply supported, other edges clamped.



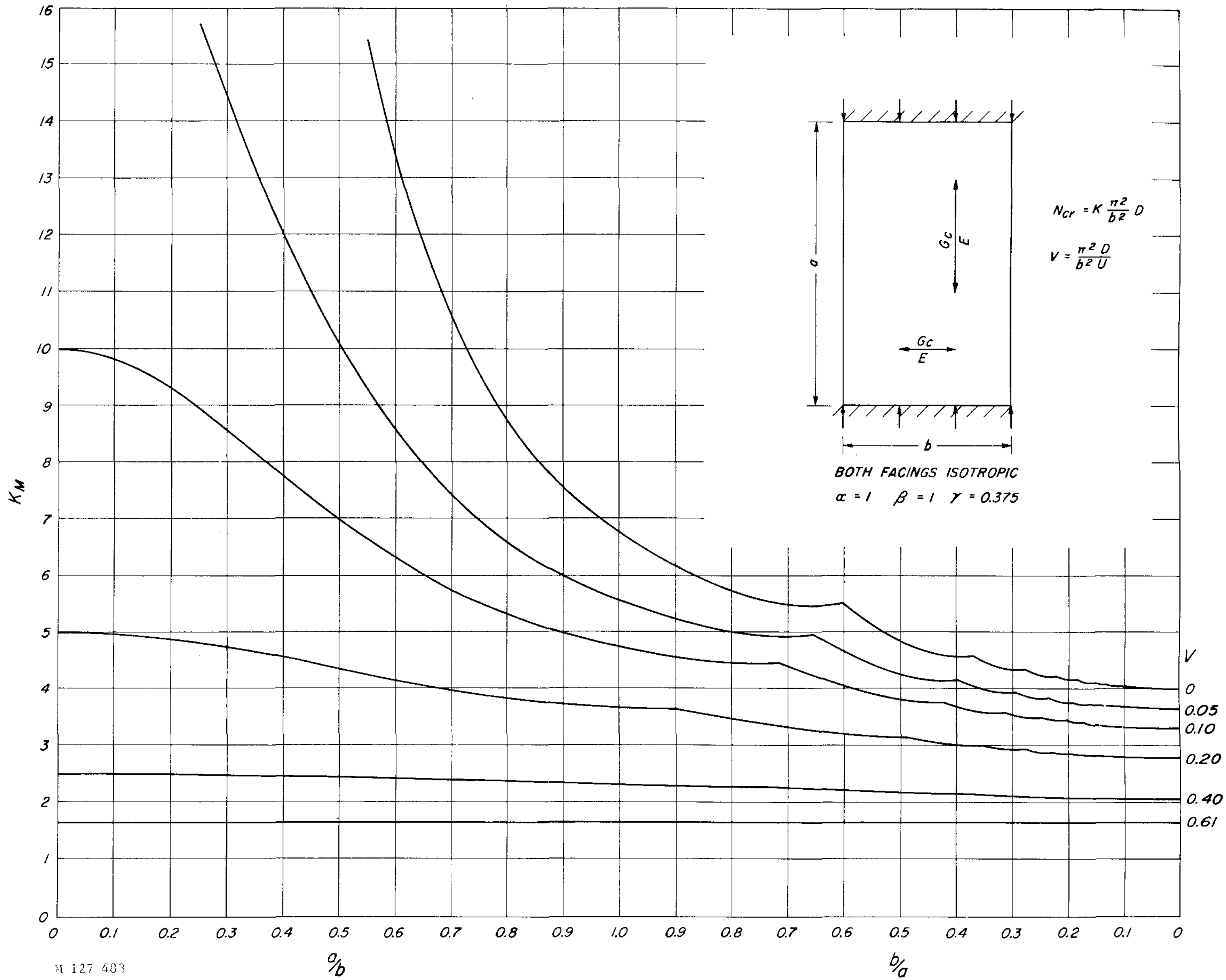
M 127 842

Figure 63.--Values of $\underline{K_1}$ and $\underline{K_2}$, (n = 1), for sandwich panels with loaded edges simply supported, other edges clamped, $\beta_1 = 1$, $\lambda_1 = 3/8$. $\beta_2 = 0.6$, $\lambda_2 = 0.2$.



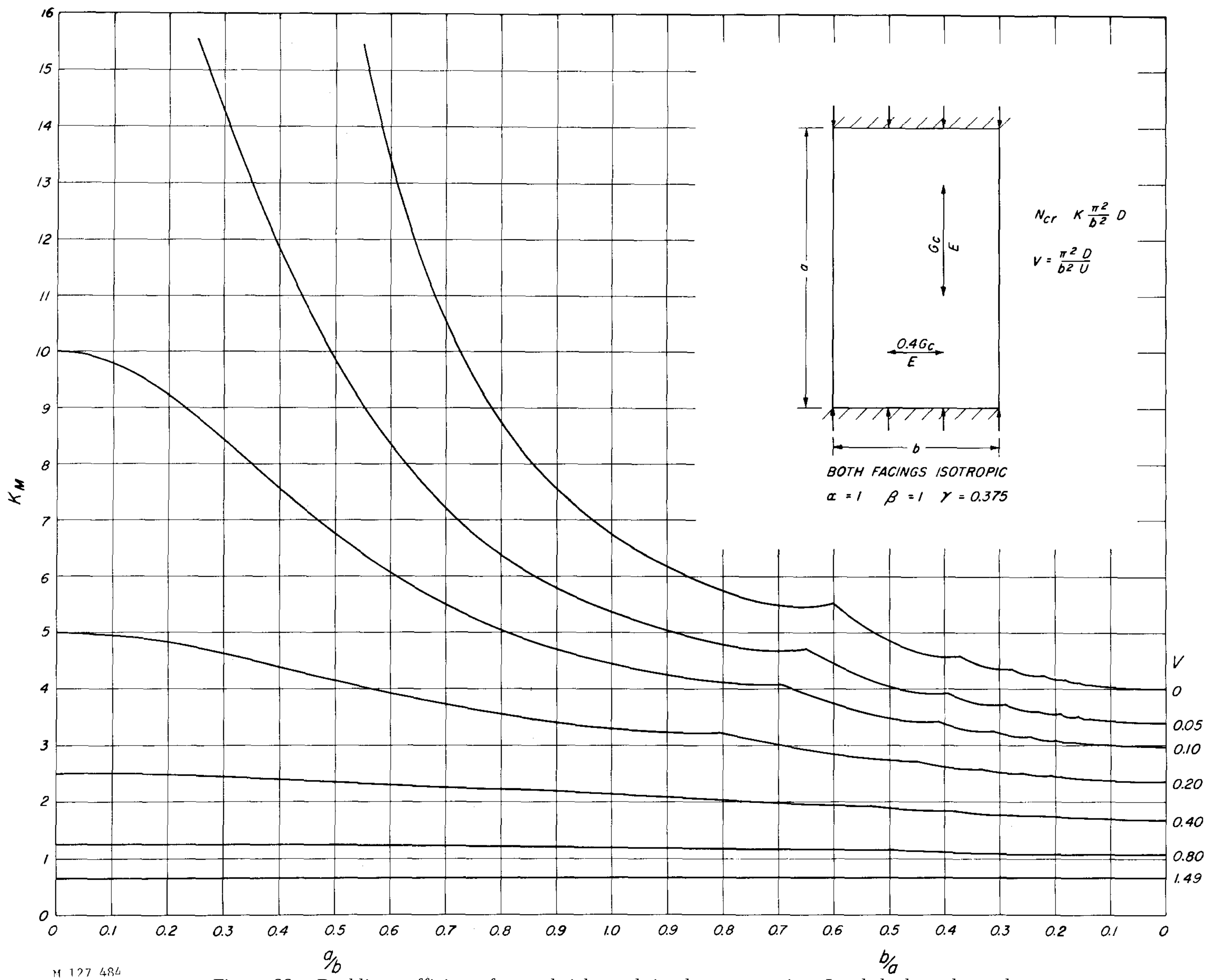
M 127 482

Figure 64.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



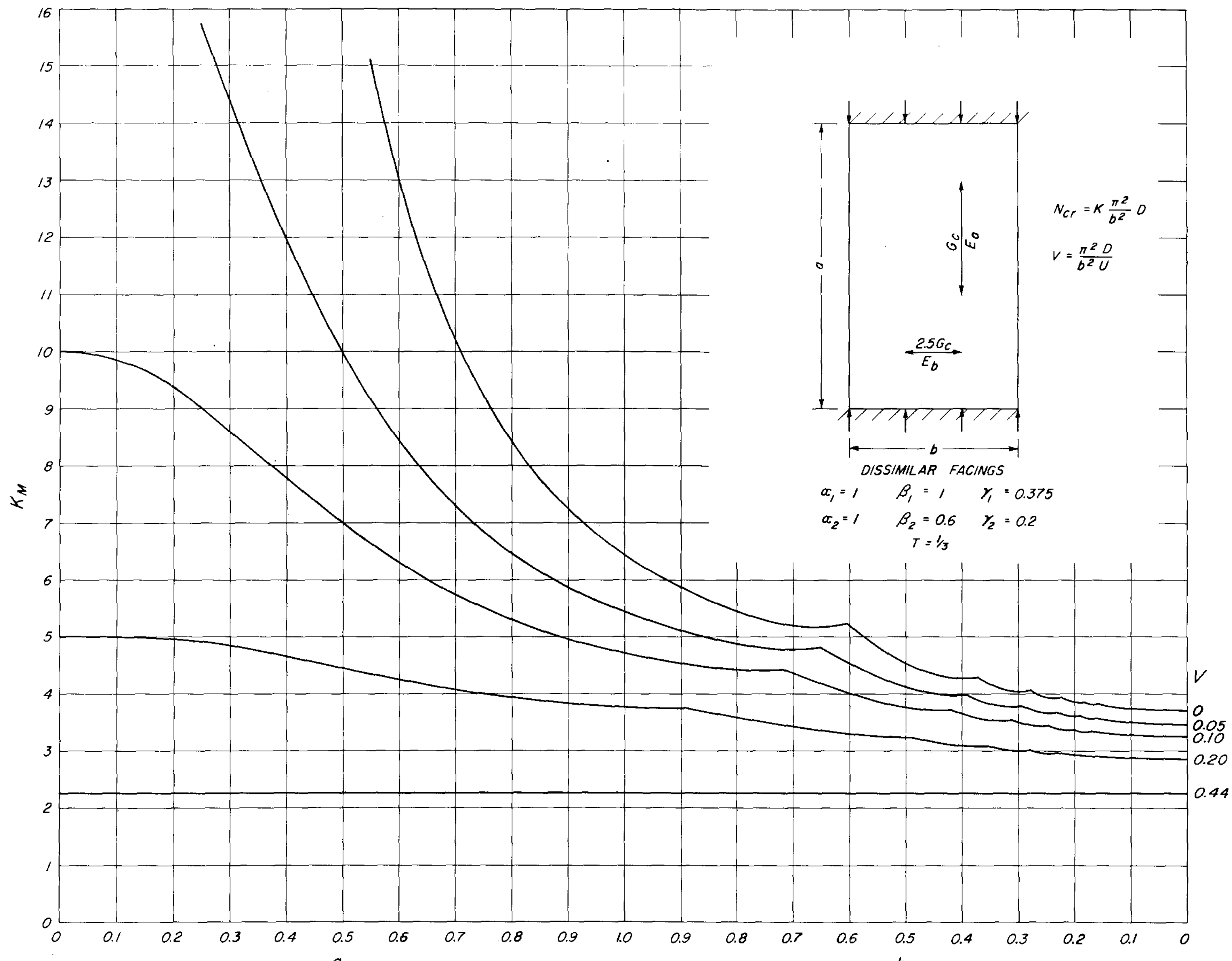
M 127 483

Figure 65.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 484

Figure 66.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 485

Figure 67.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

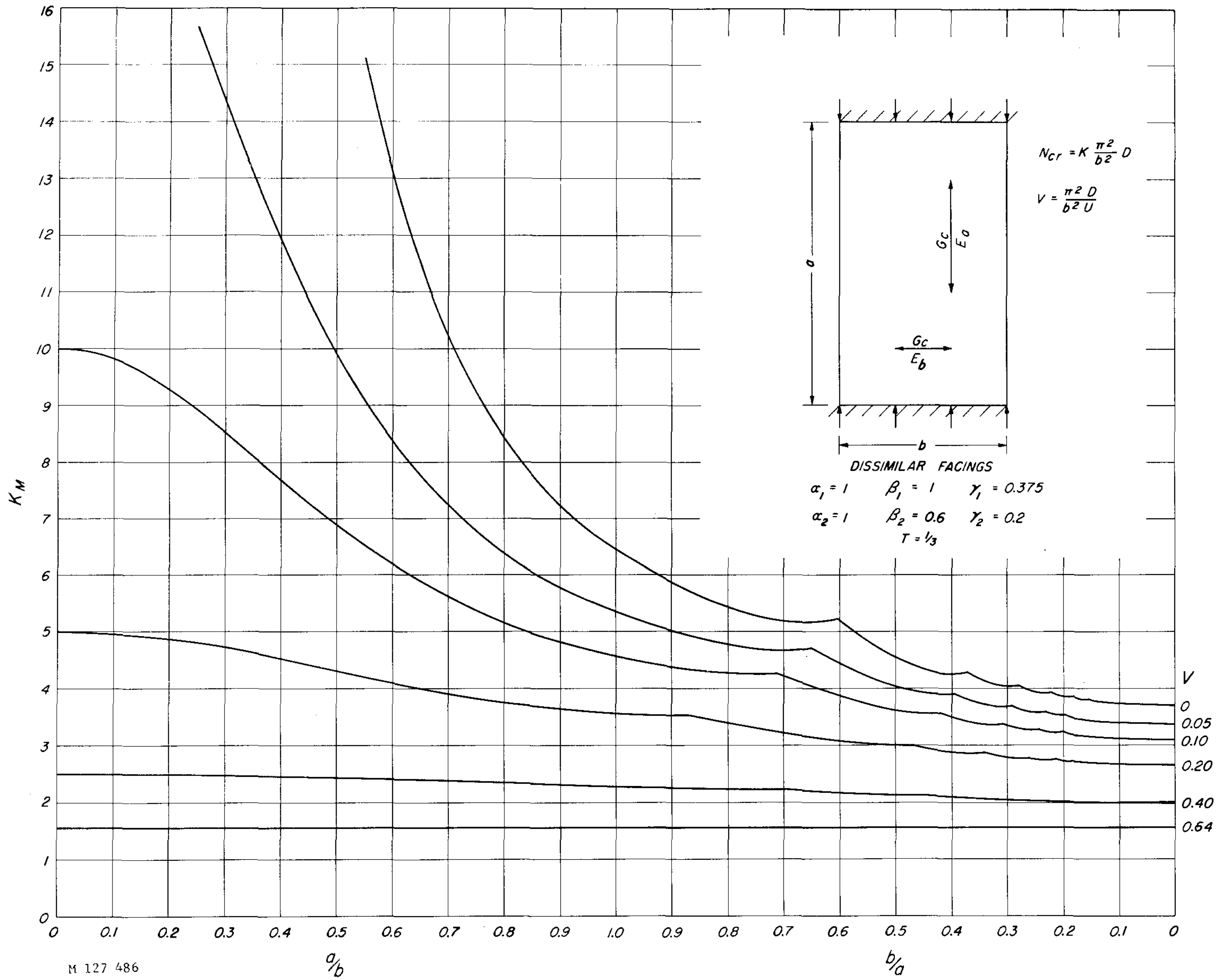


Figure 68.--Bucklingcoefficients for sandwichpanels in edge compression. Loaded edges clamped, other edges simply supported.

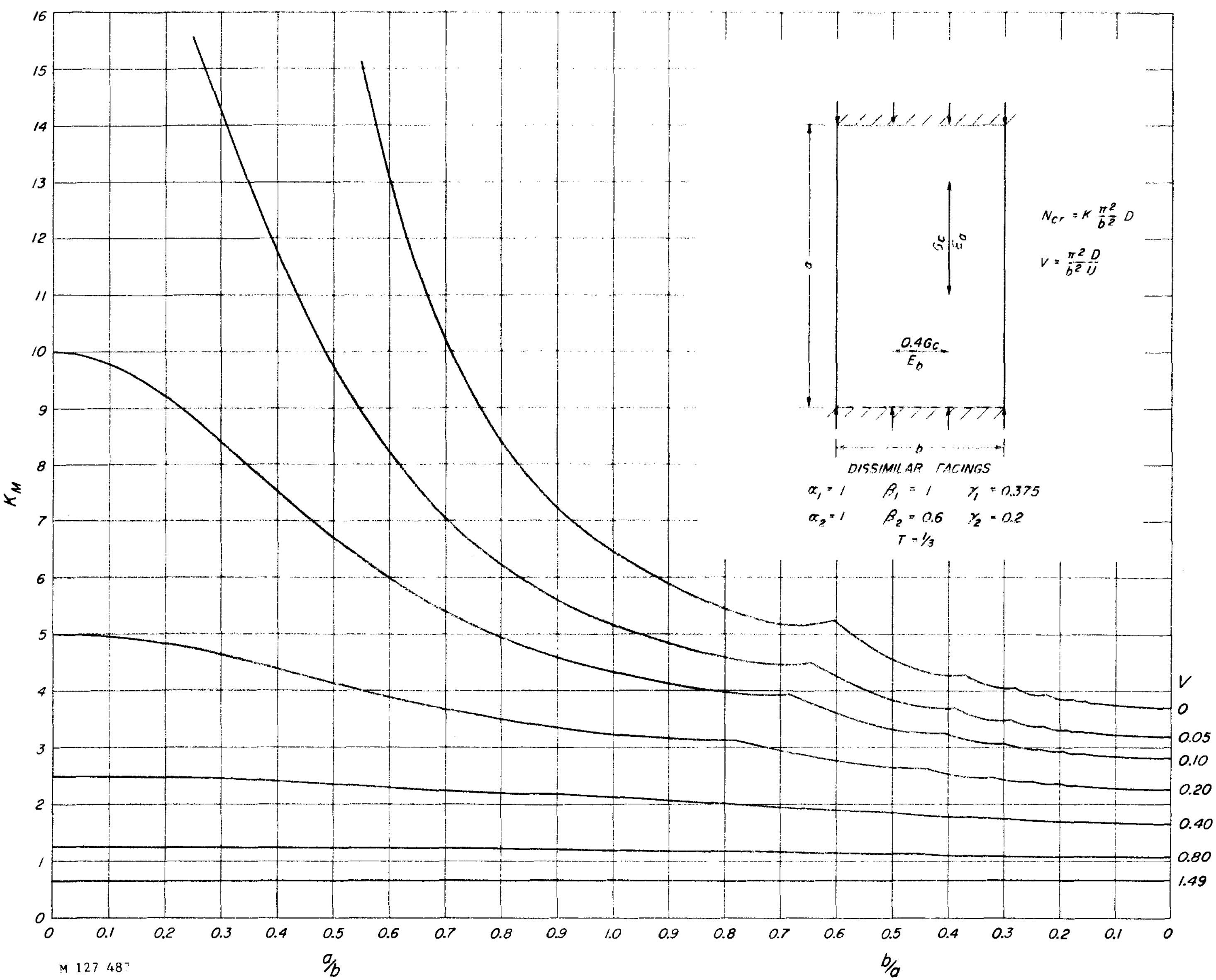
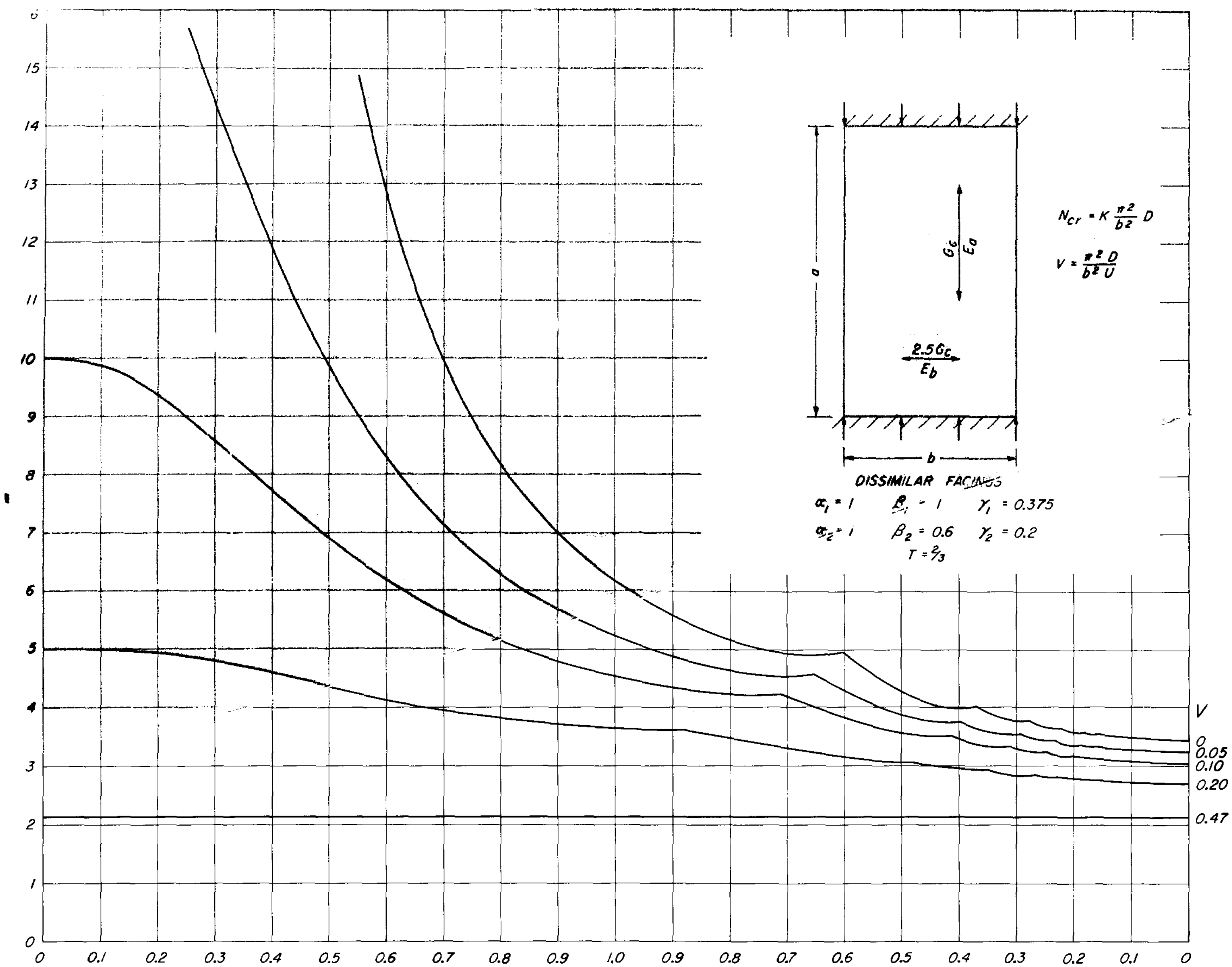
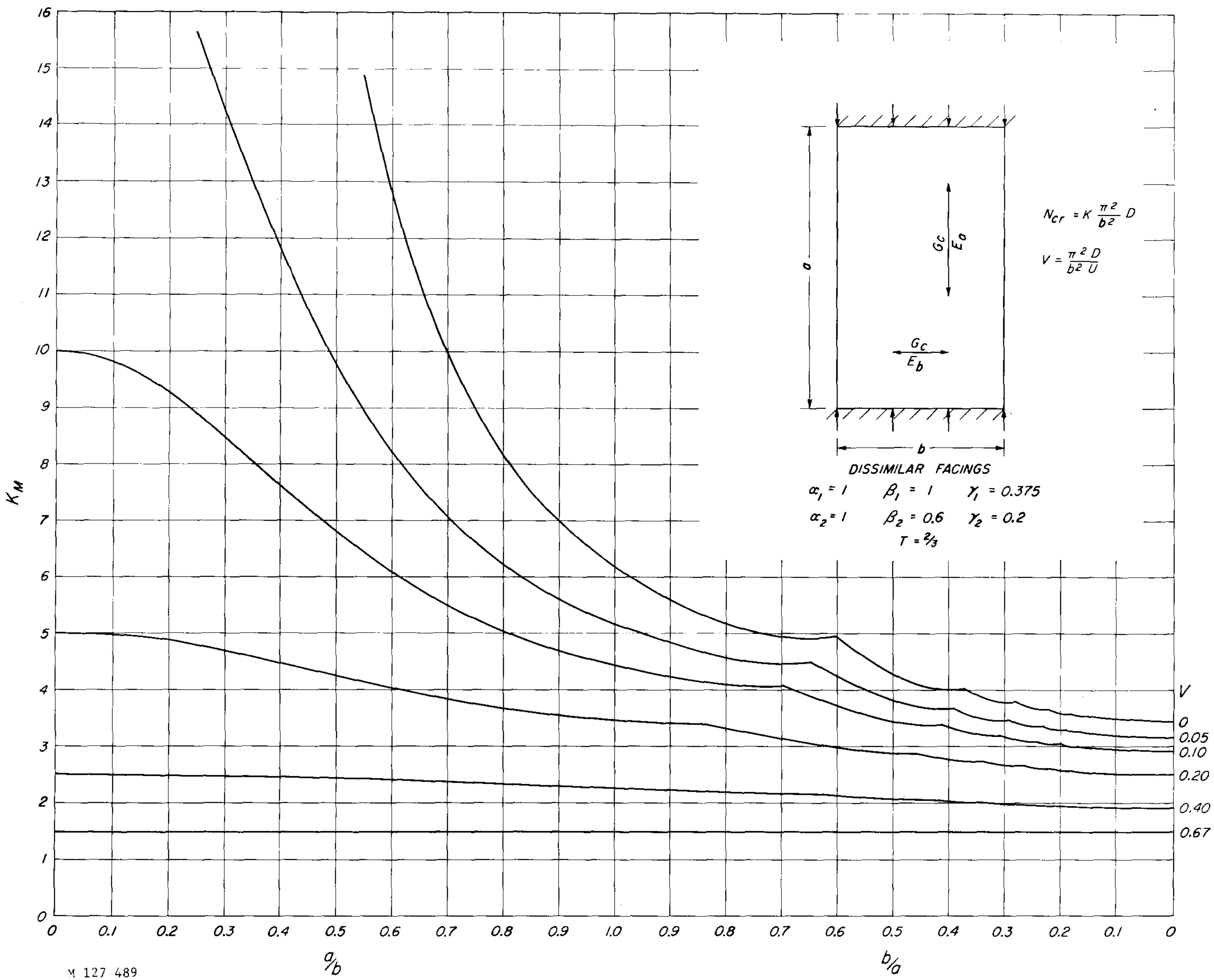


Figure 69.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



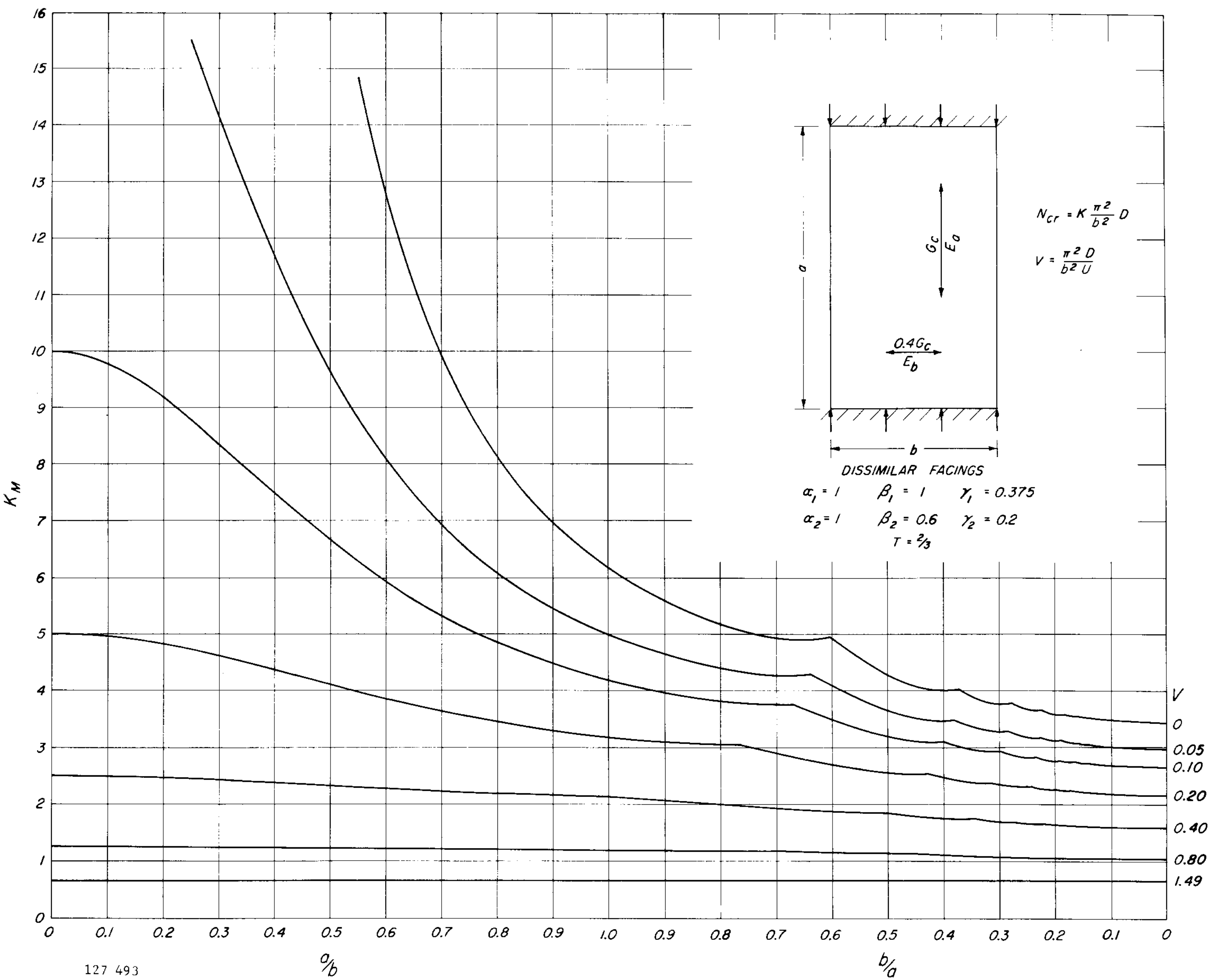
M 127 488

Figure 70.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



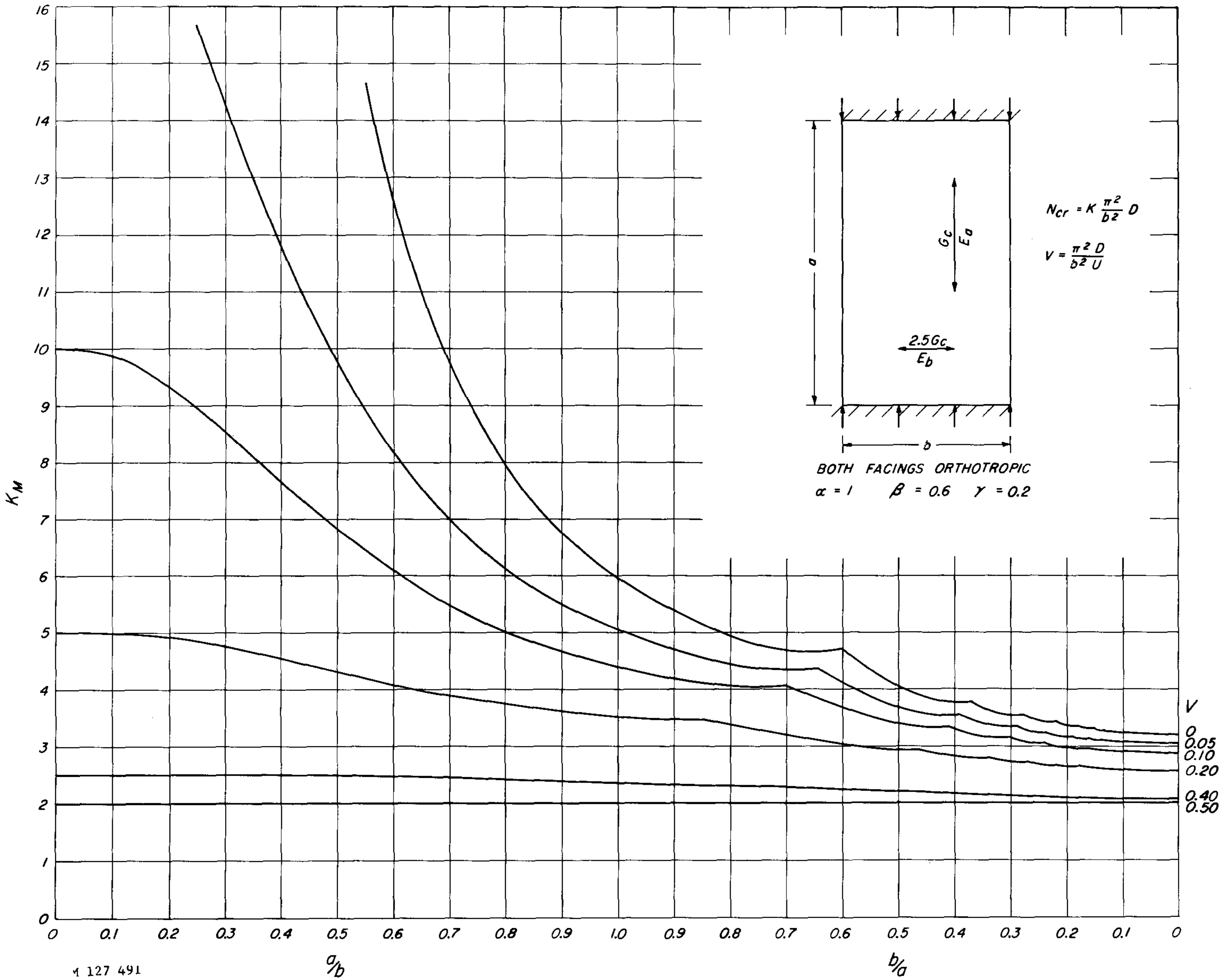
M 127 489

Figure 71.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



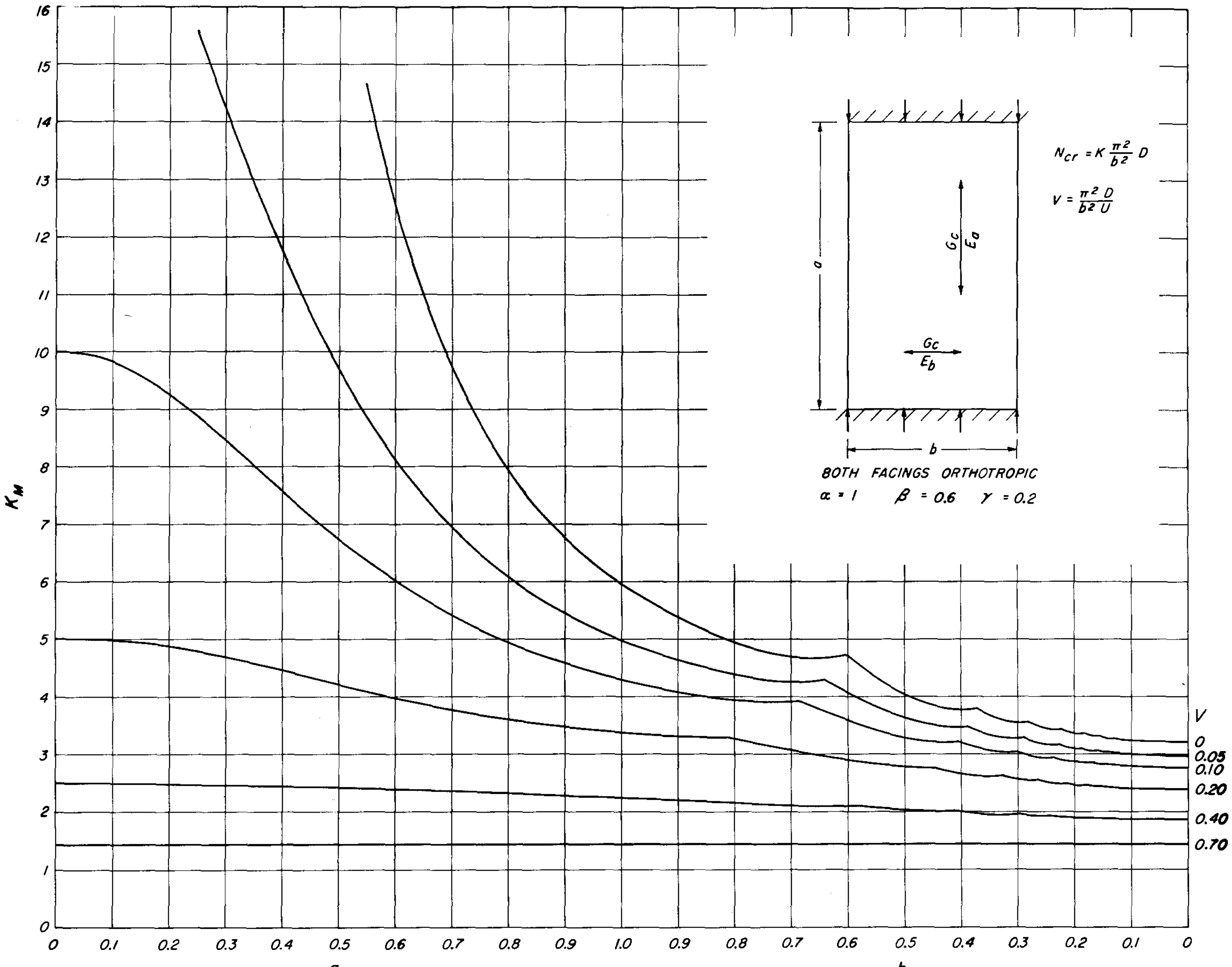
127 493

Figure 72.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



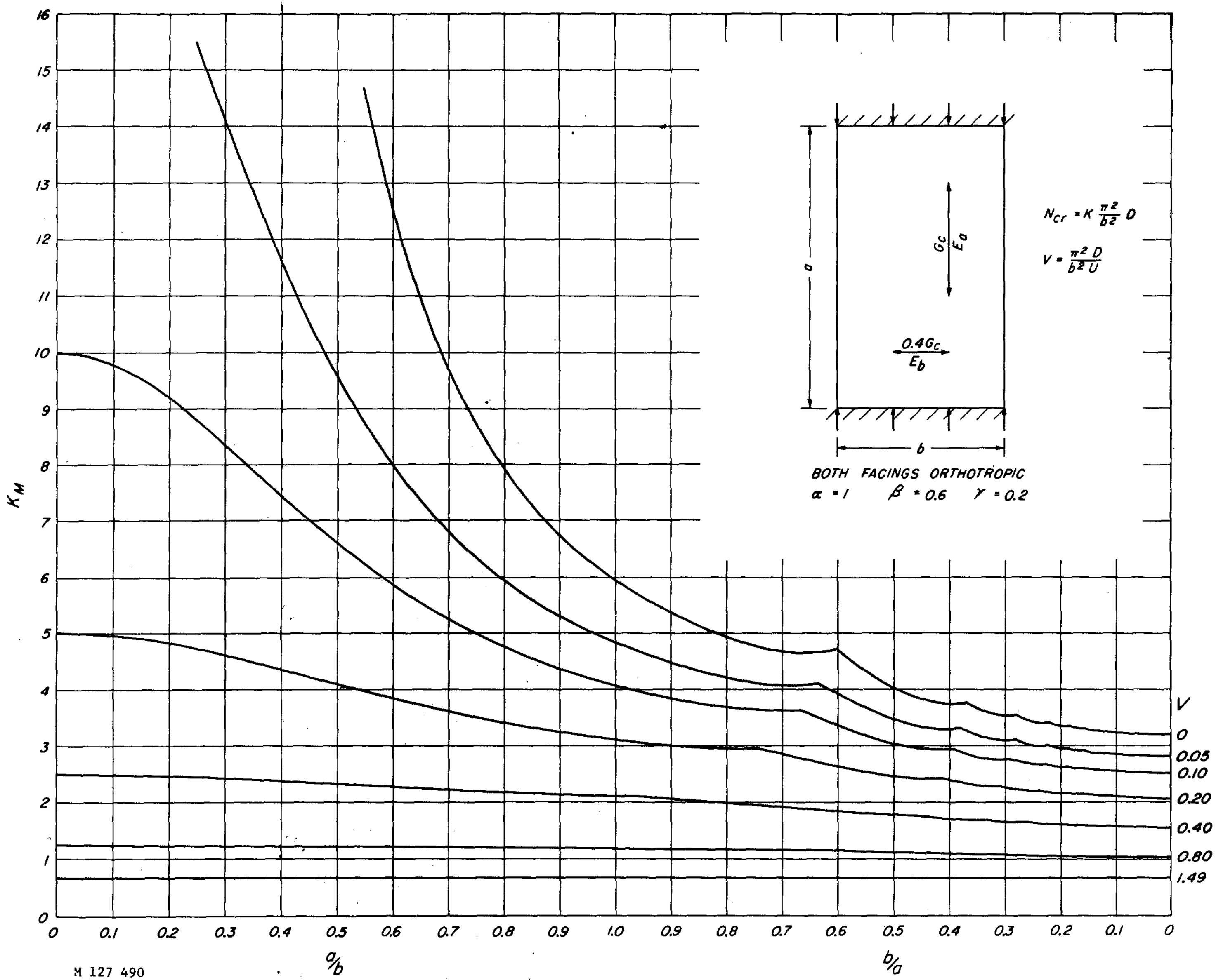
M 127 491

Figure 73.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



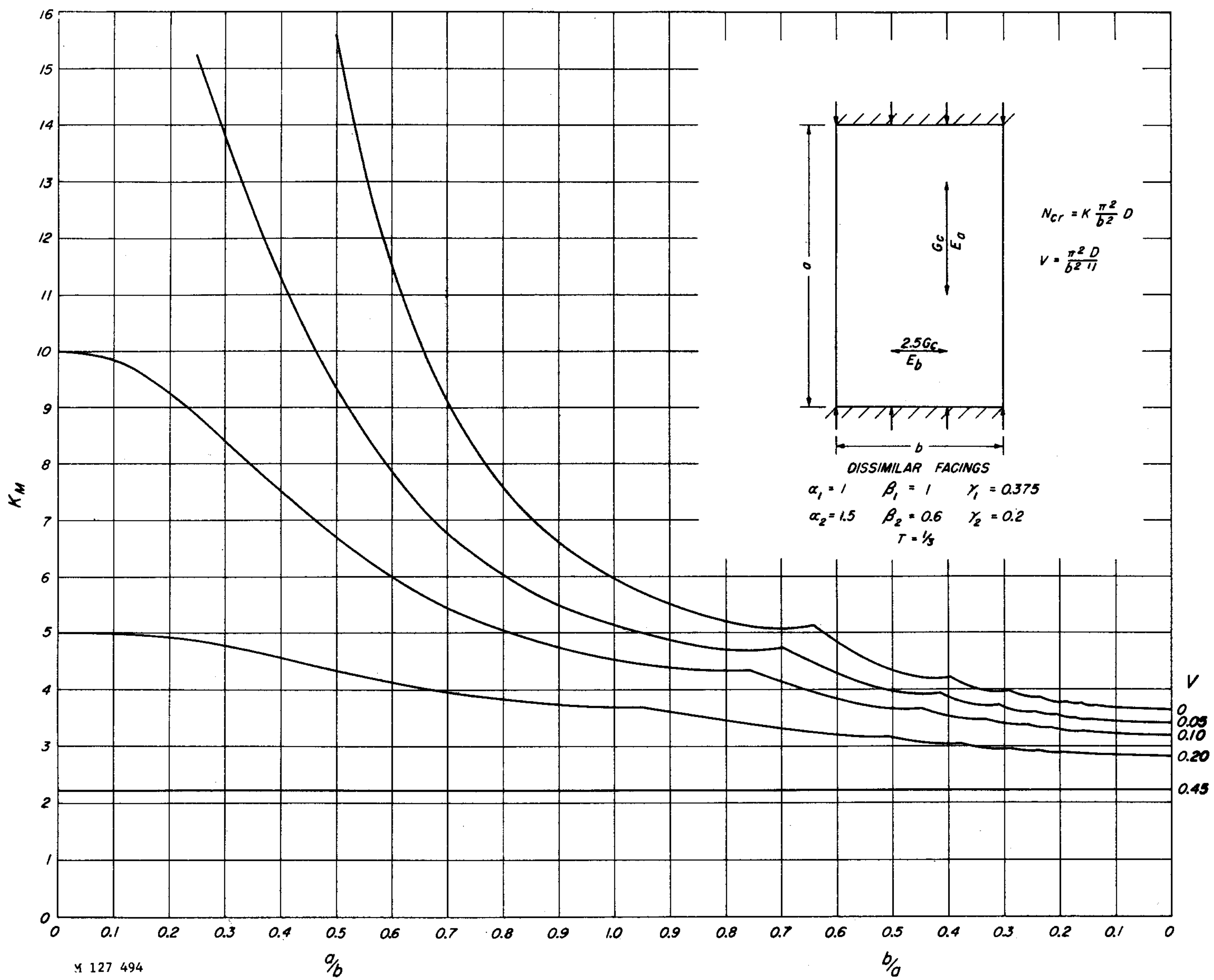
M 127 492

Figure 74.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 490

Figure 75.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped. other edges simply supported.



M 127 494

Figure 76.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

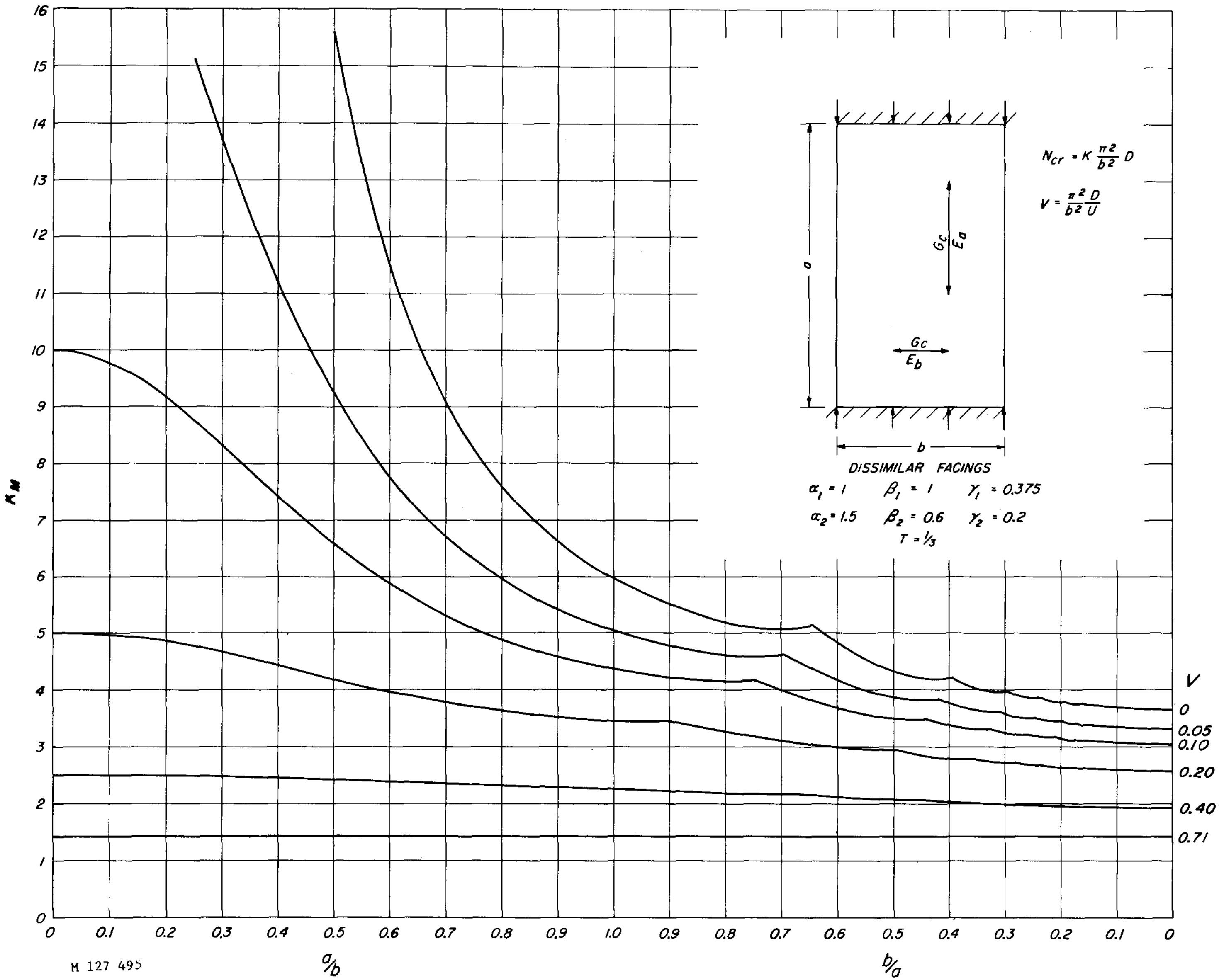
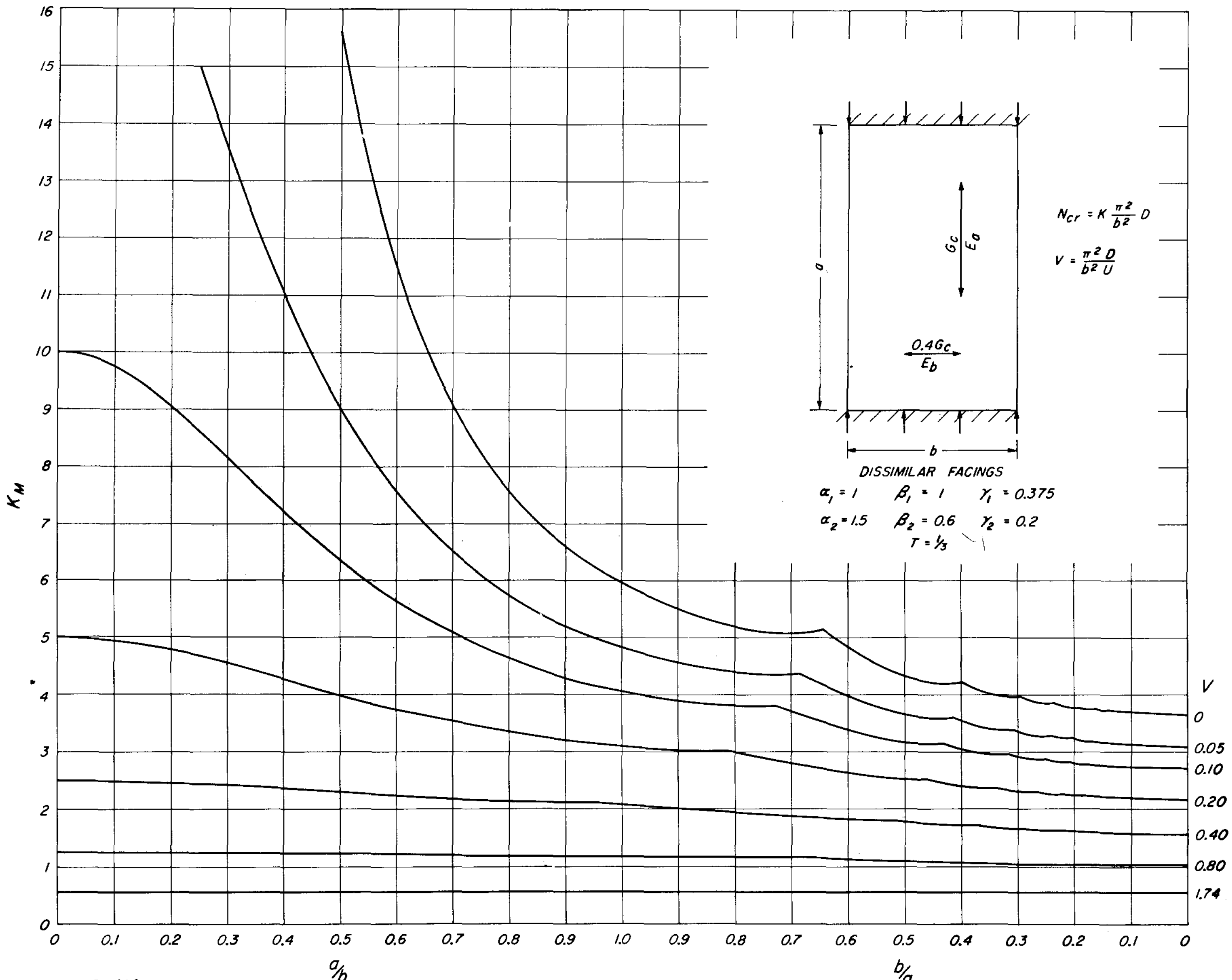


Figure 77.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 496

Figure 78.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

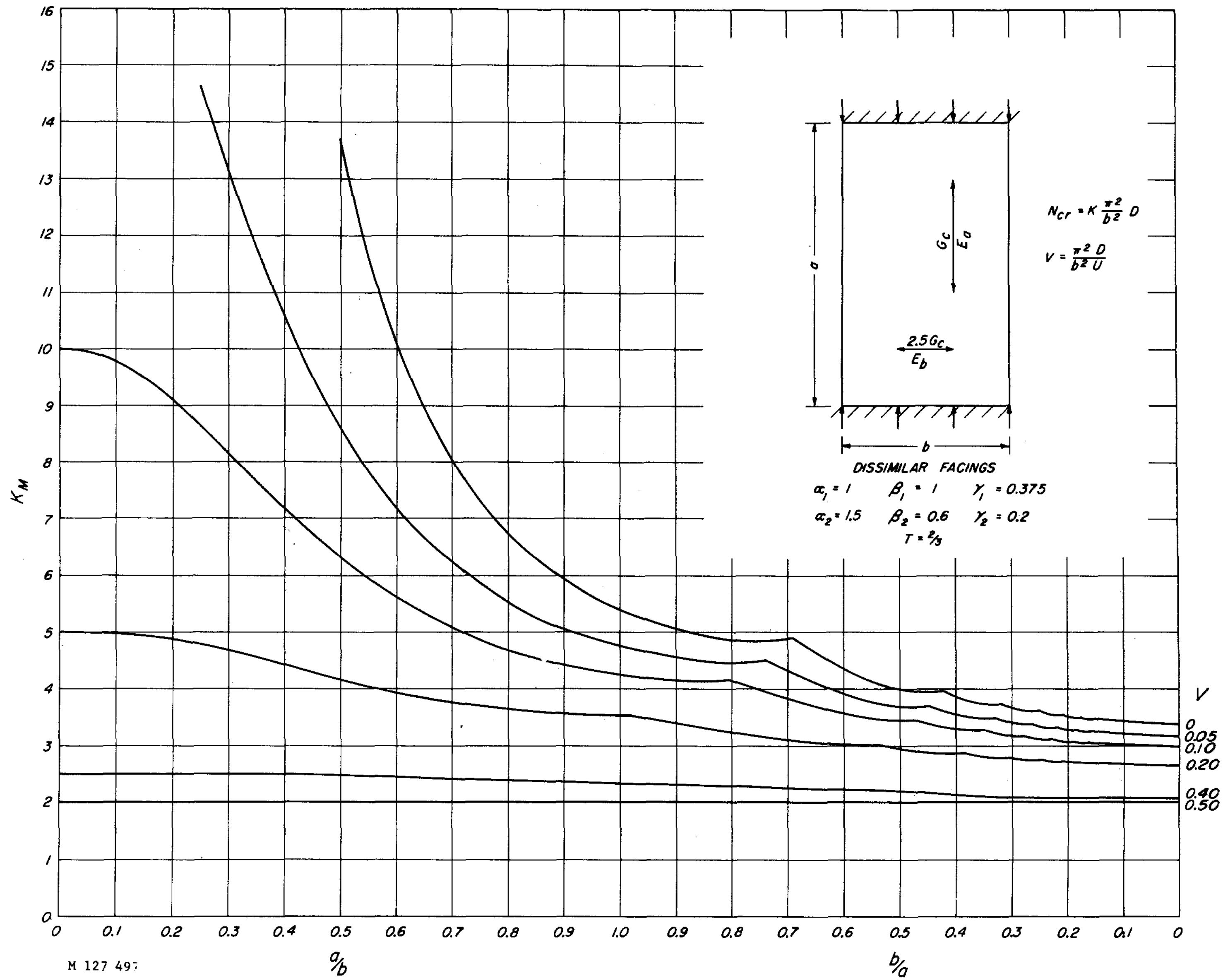


Figure 79.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

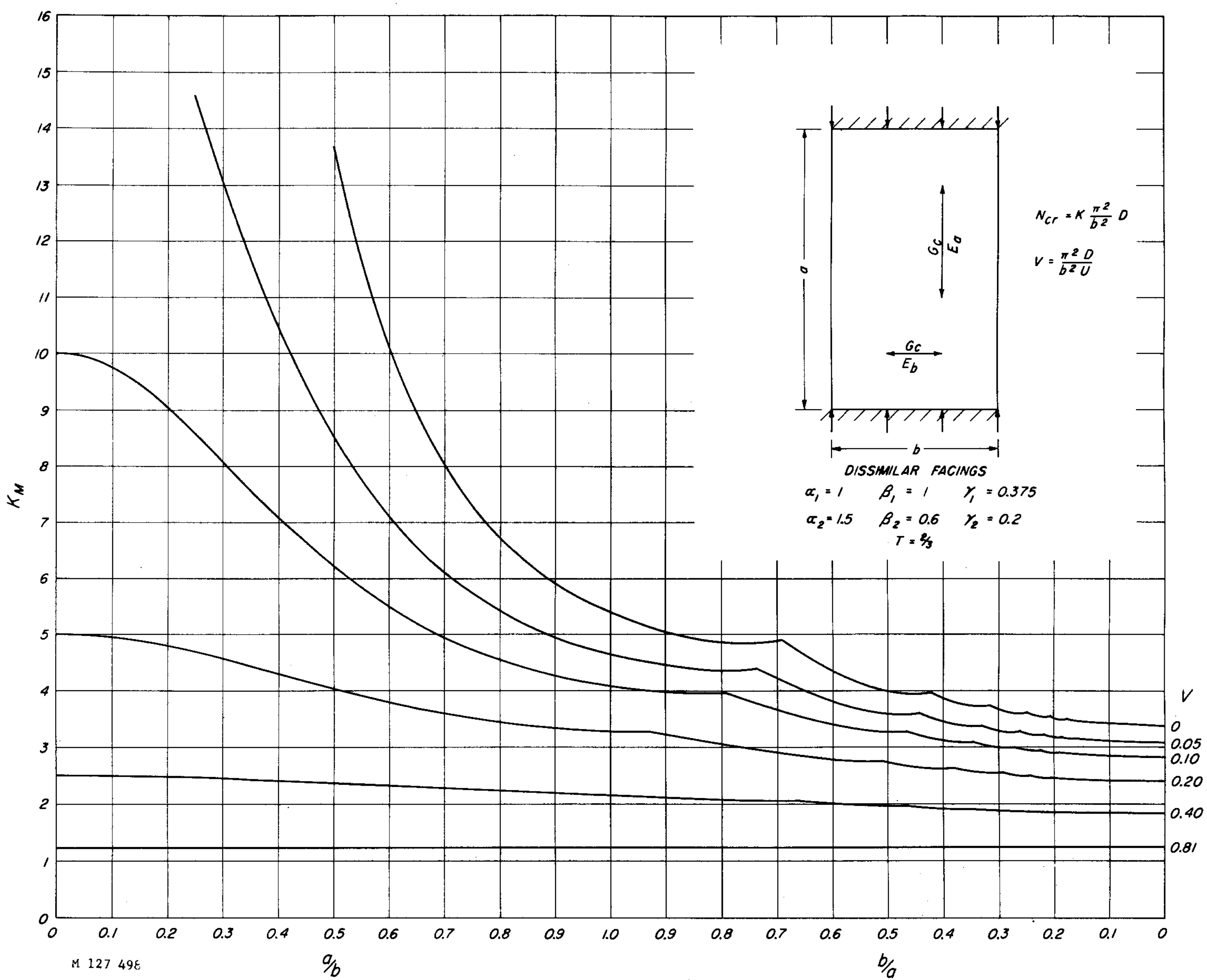
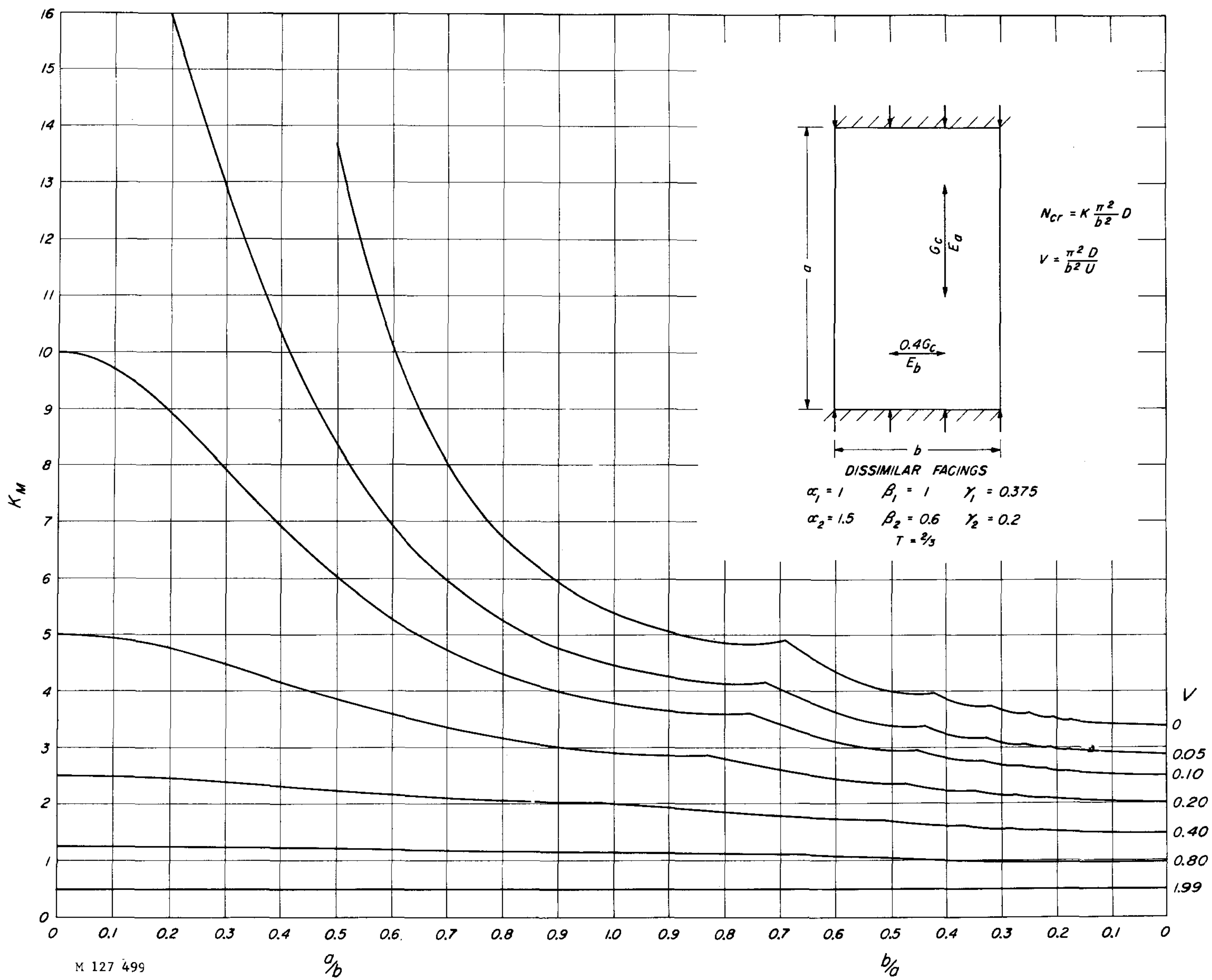


Figure 80.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 499

Figure 81.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

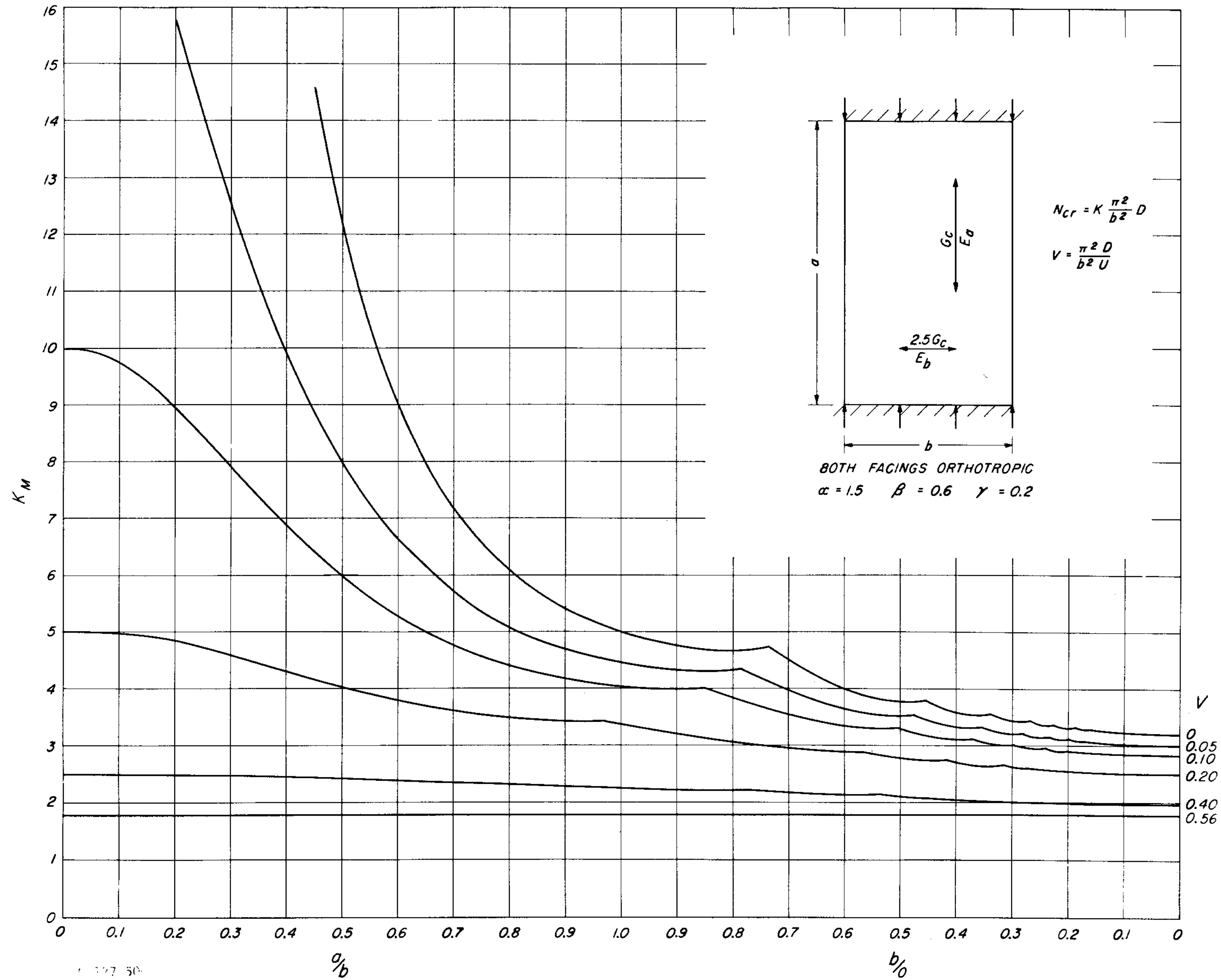


Figure 82.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

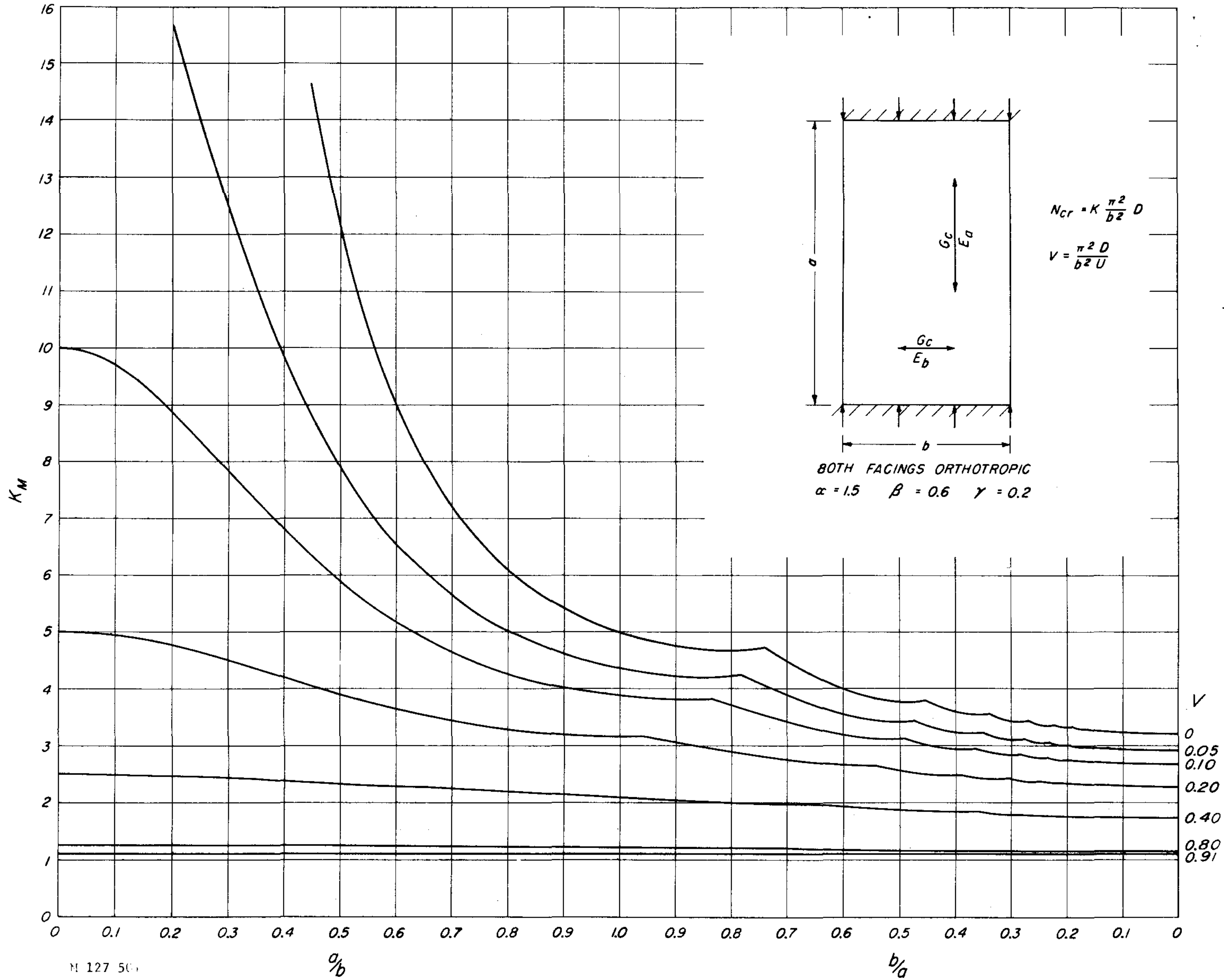
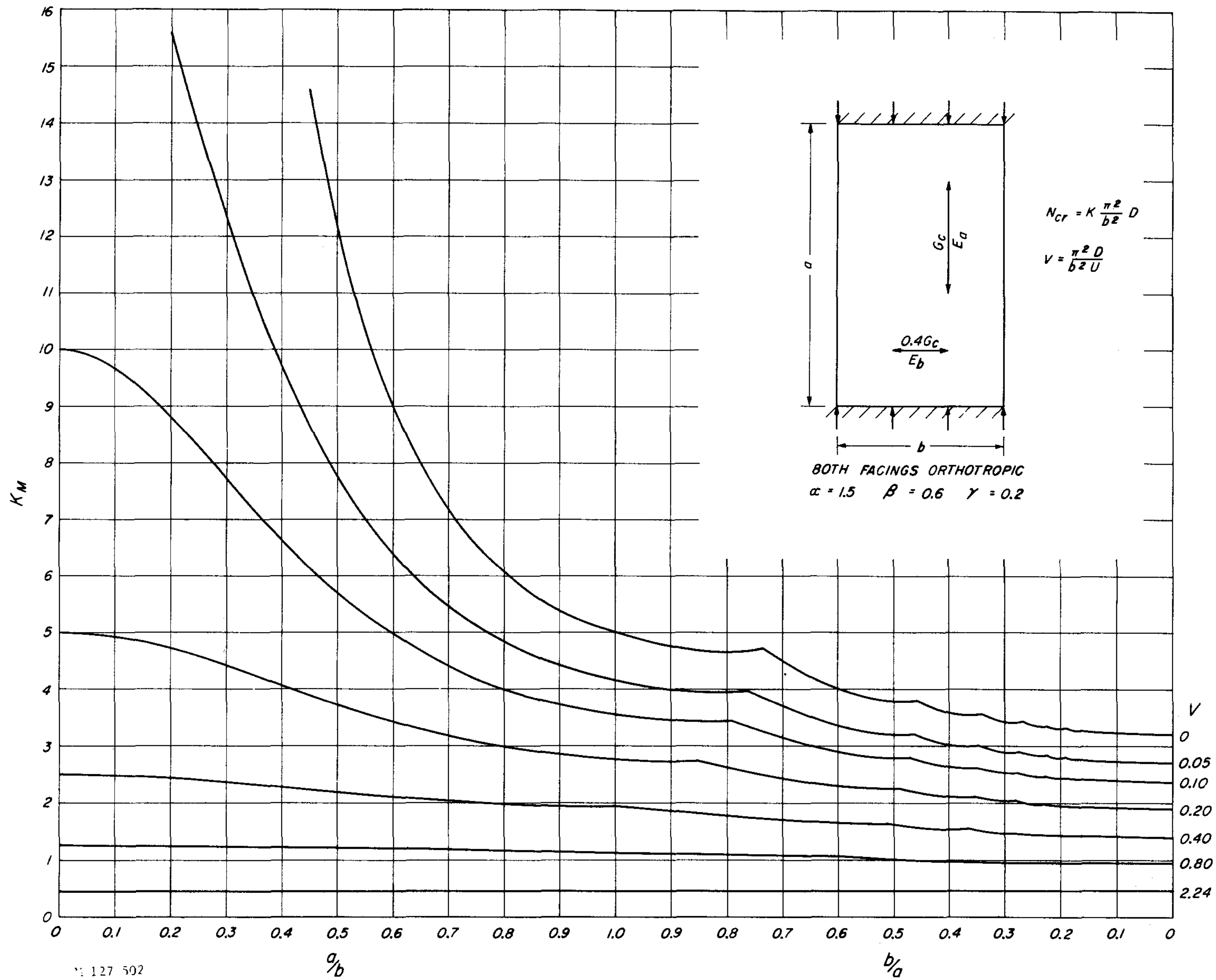
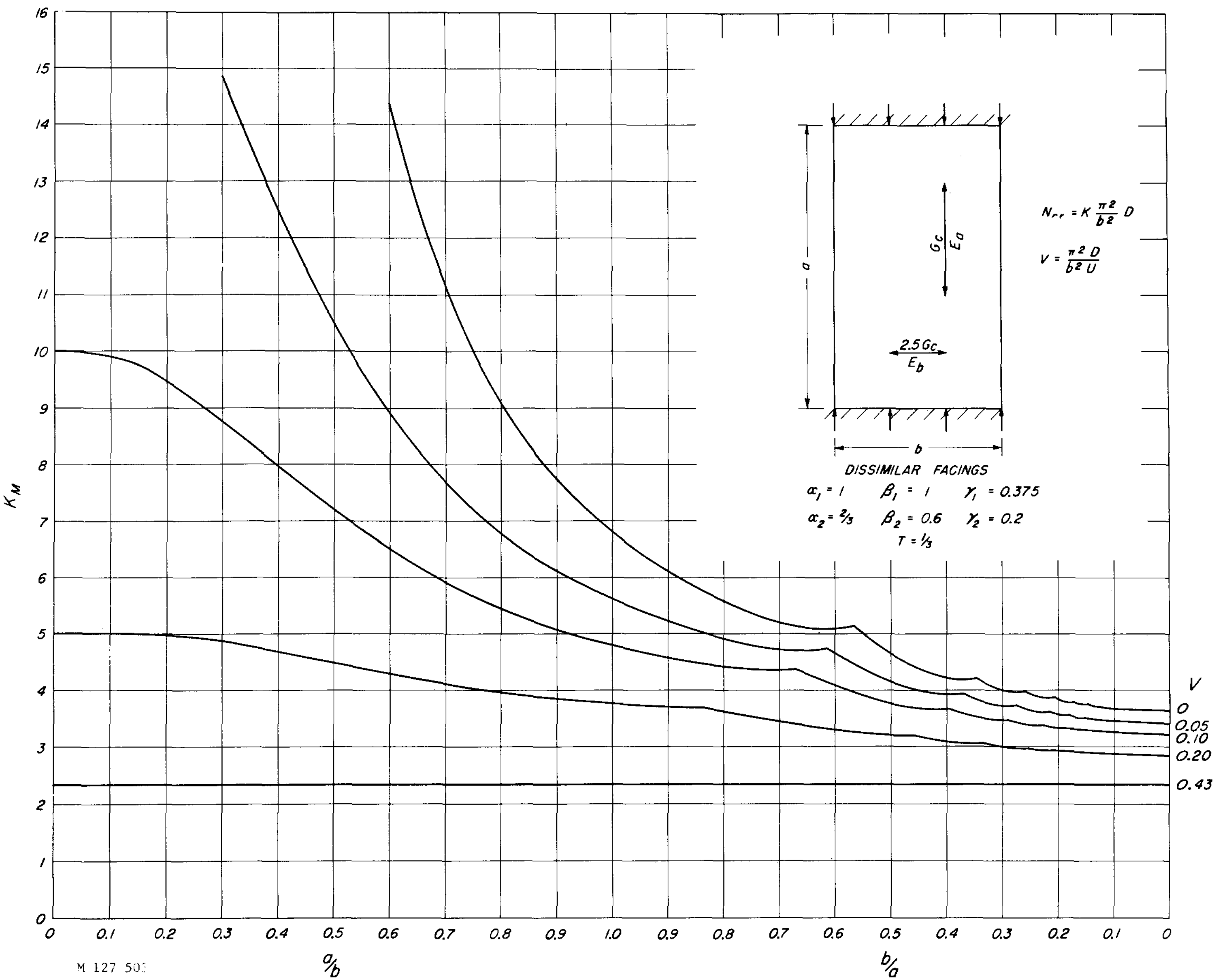


Figure 83.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



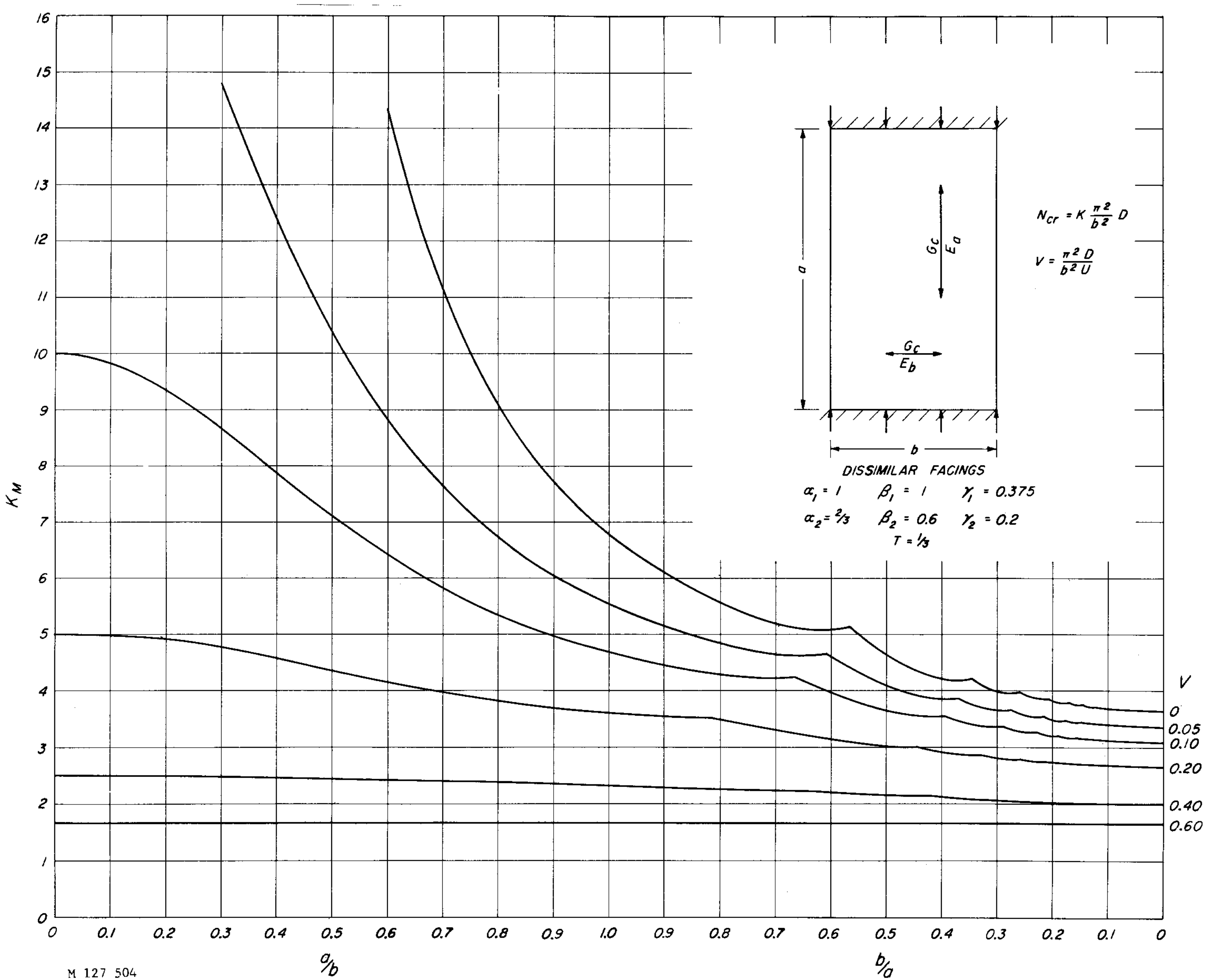
M 127 502

Figure 84.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 503

Figure 85.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 504

Figure 86.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported

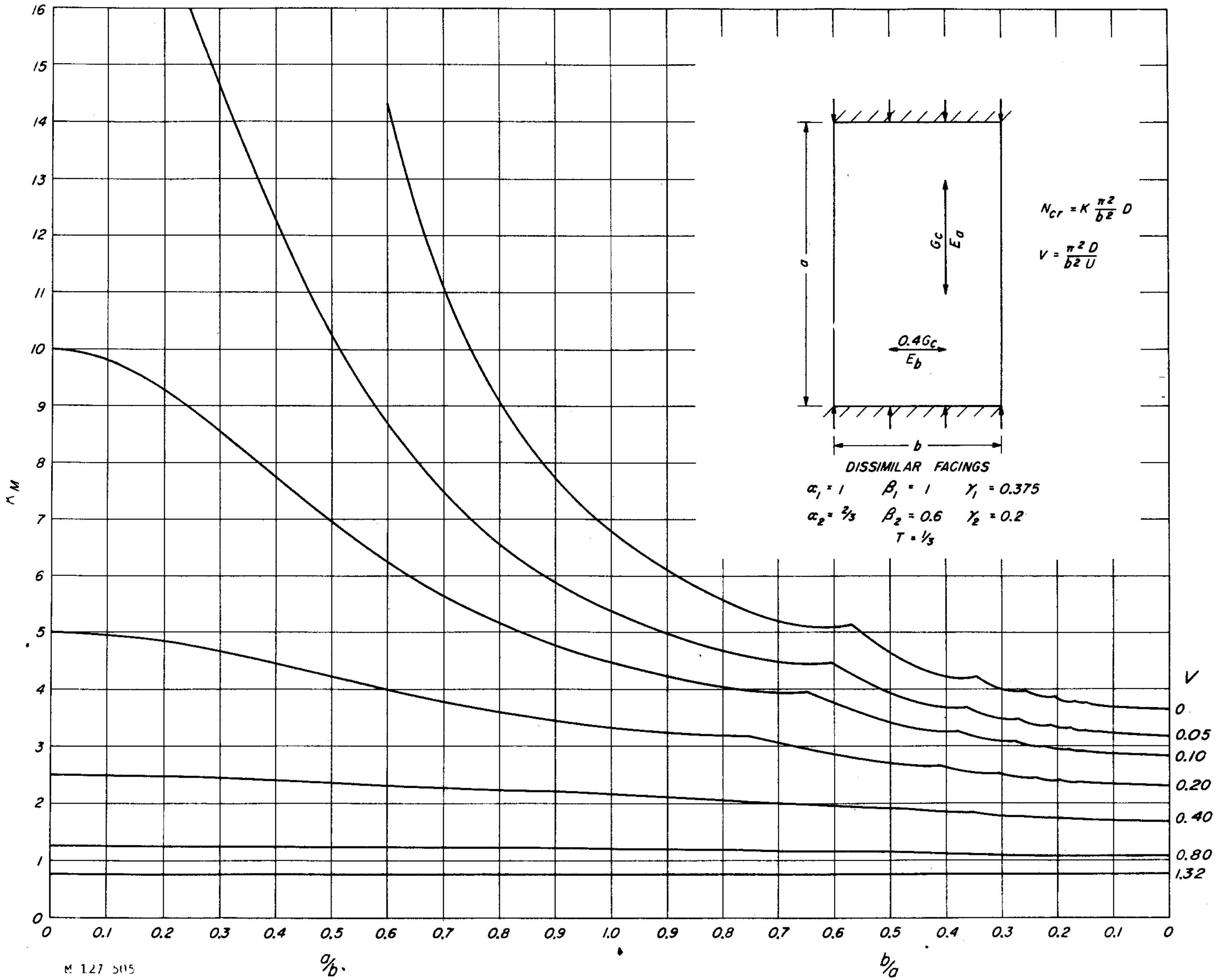
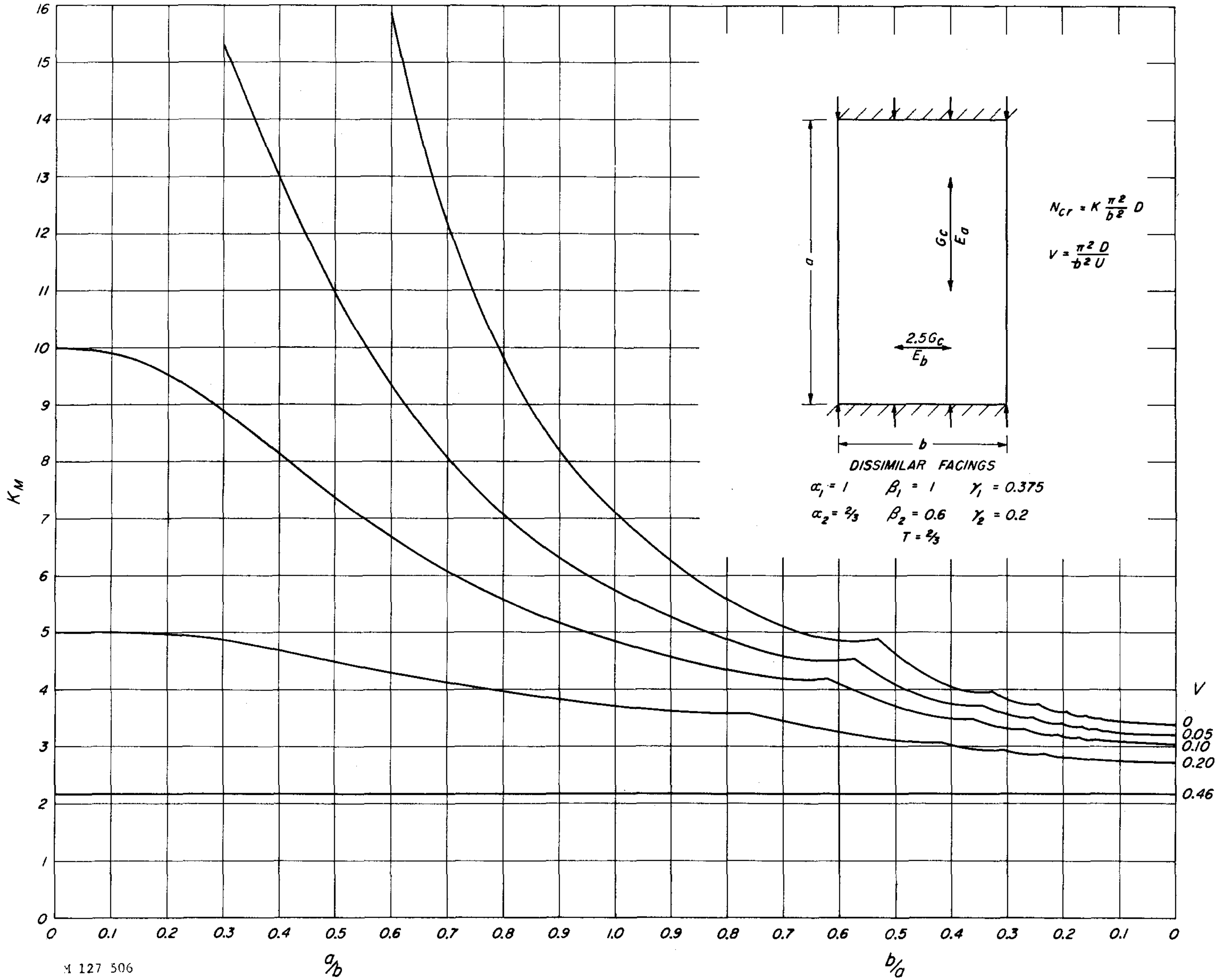
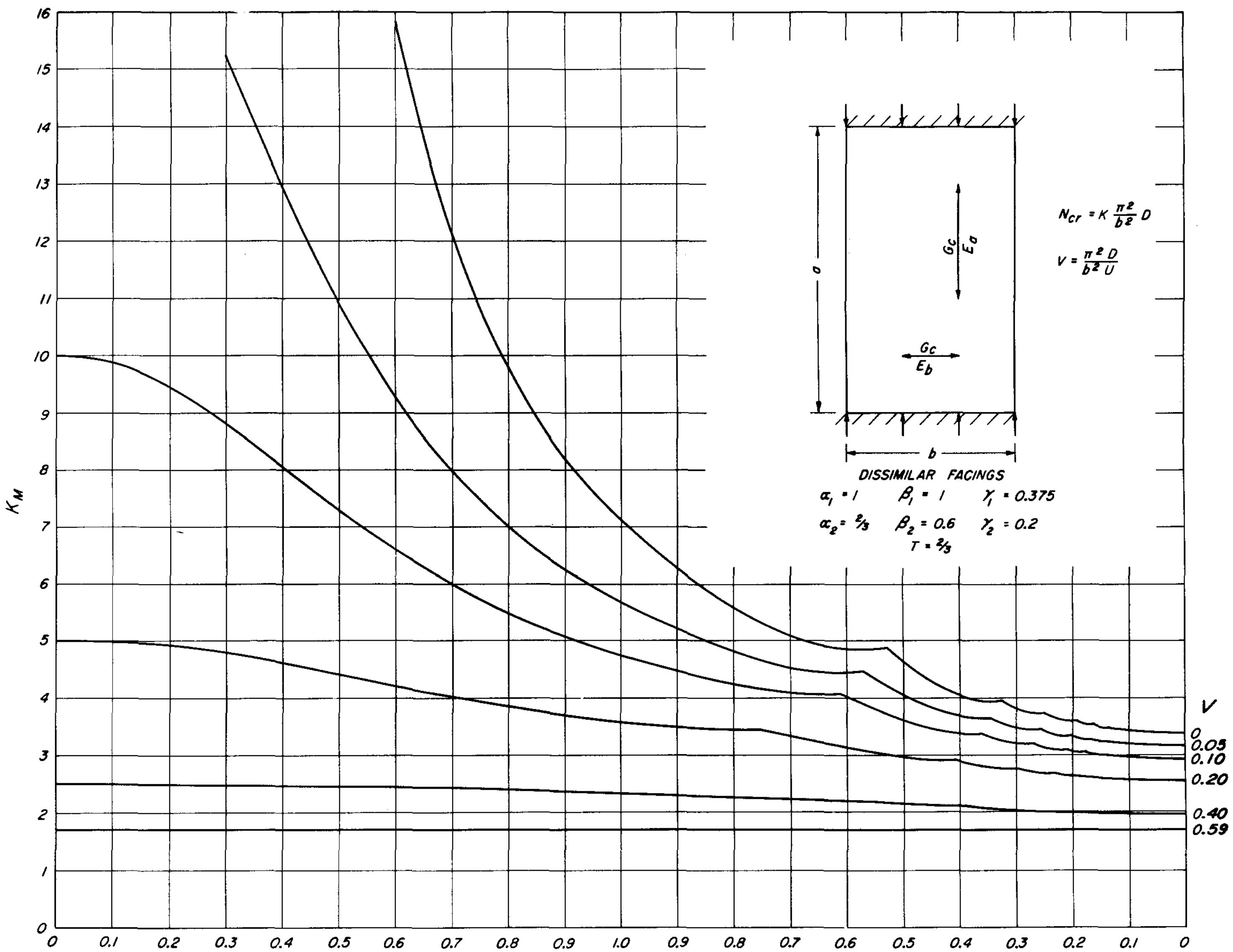


Figure 87.--Buckling coefficients for sandwich panels in edge compressio. Loaded edges clamped, other edges simply supported.



M 127 506

Figure 88.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



M 127 507

Figure 89.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

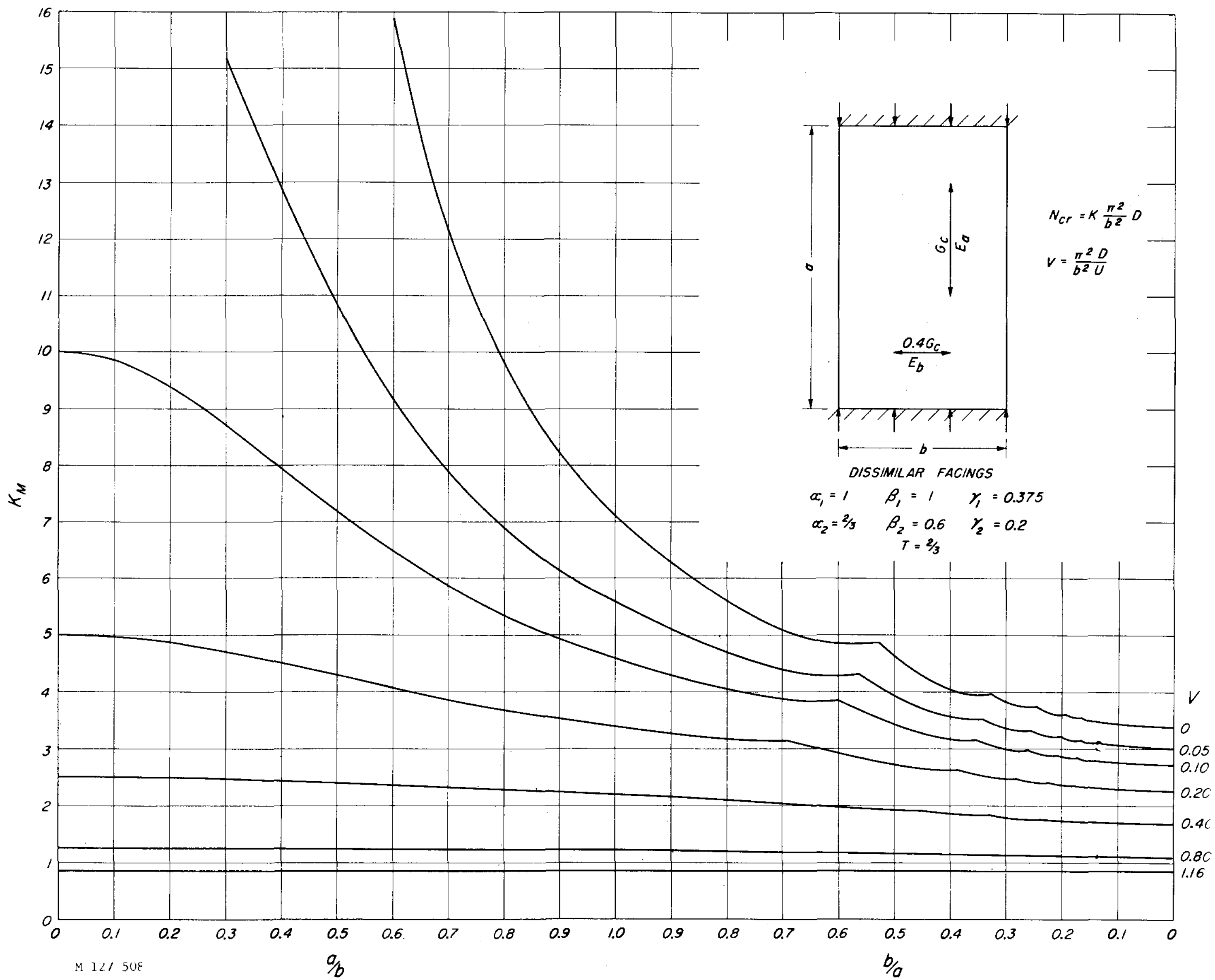


Figure 90.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.

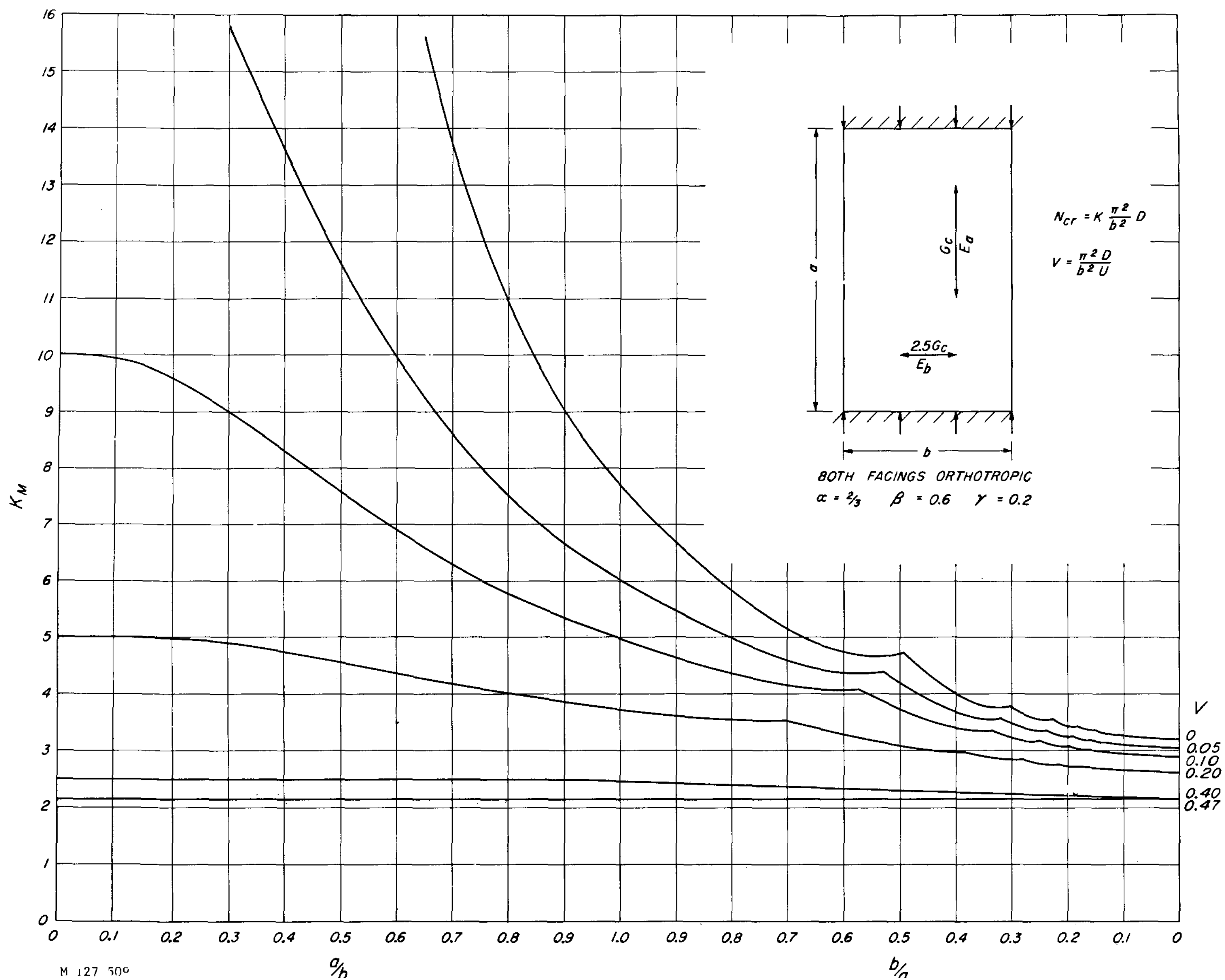
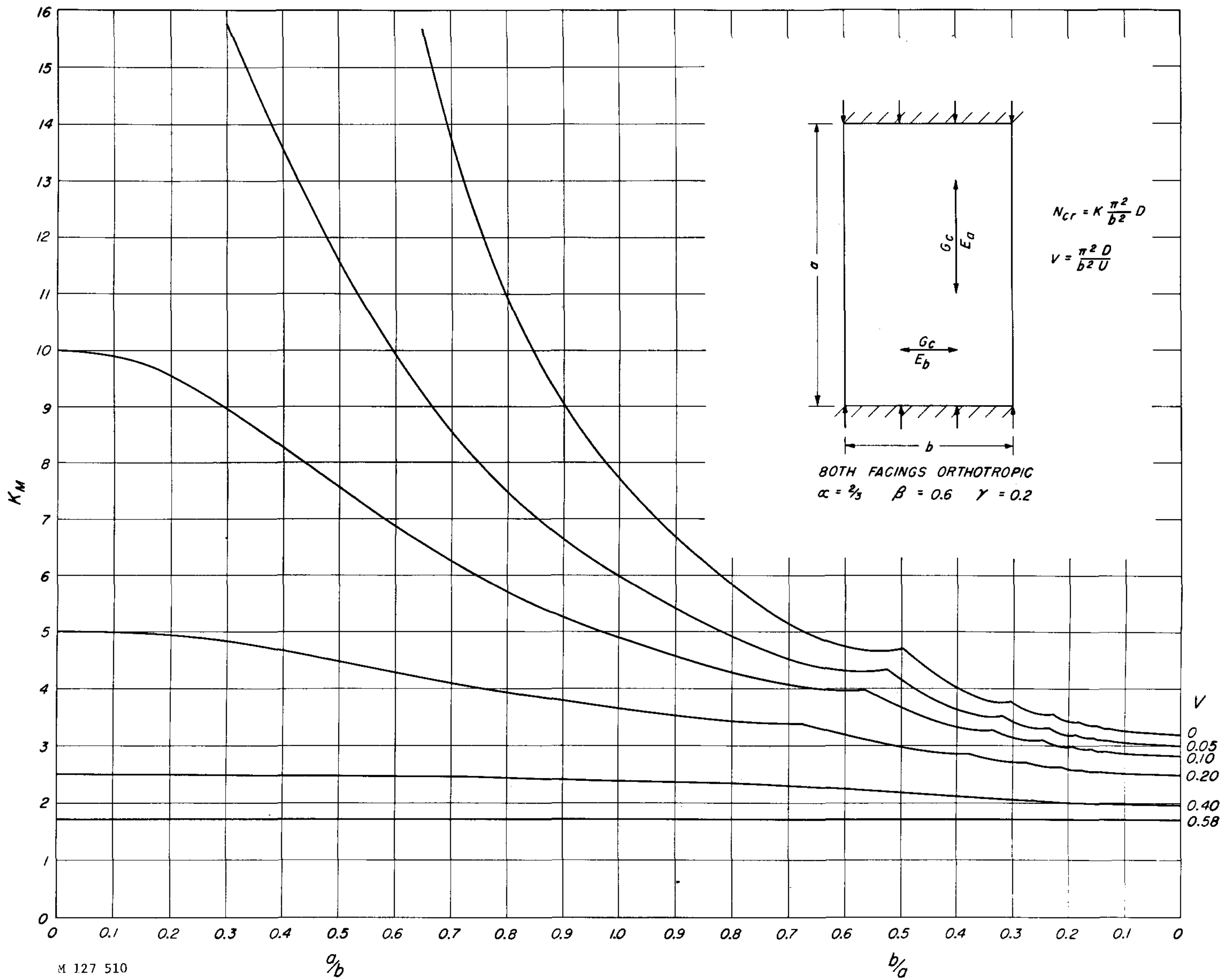
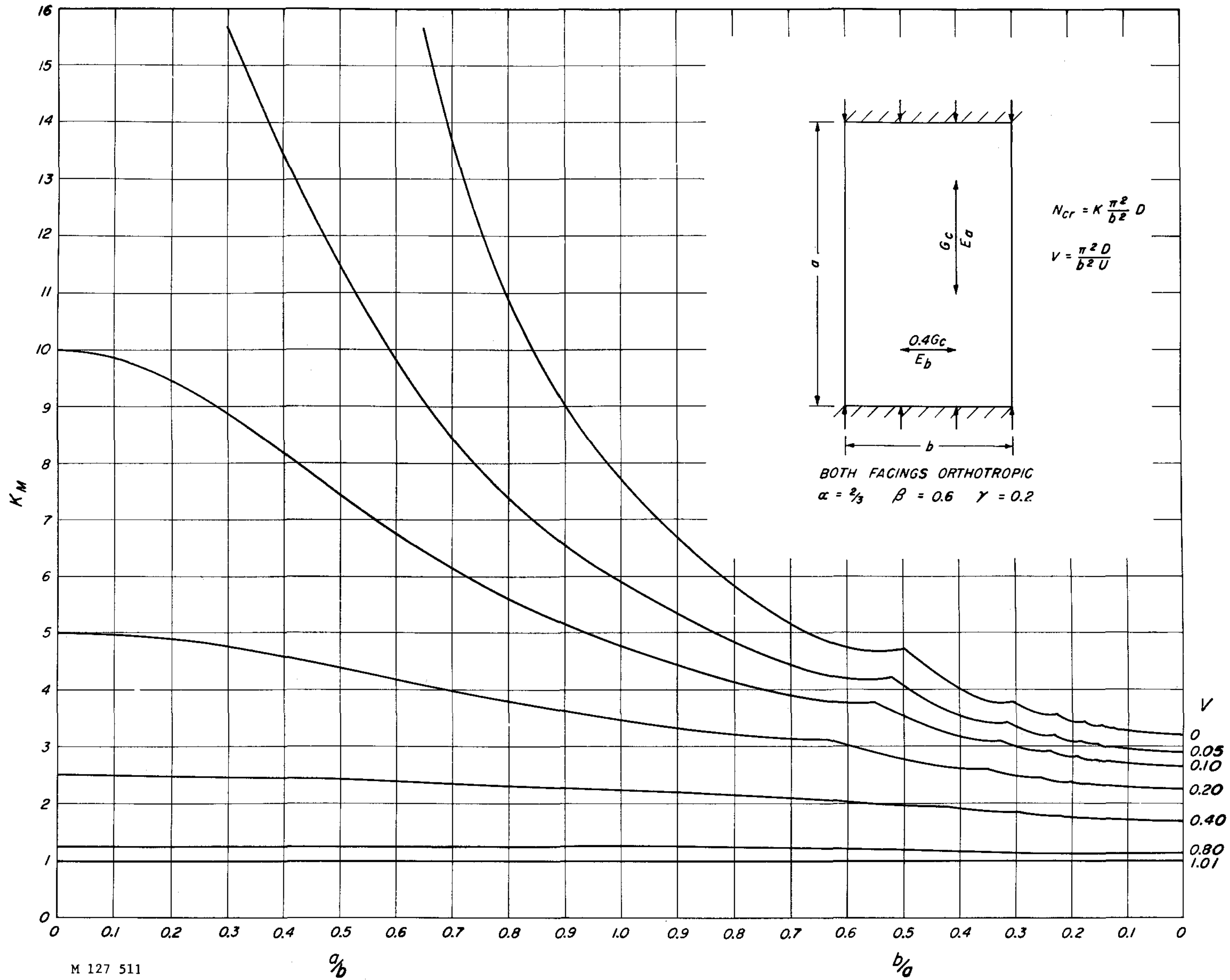


Figure 91.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped. other edges simply supported.



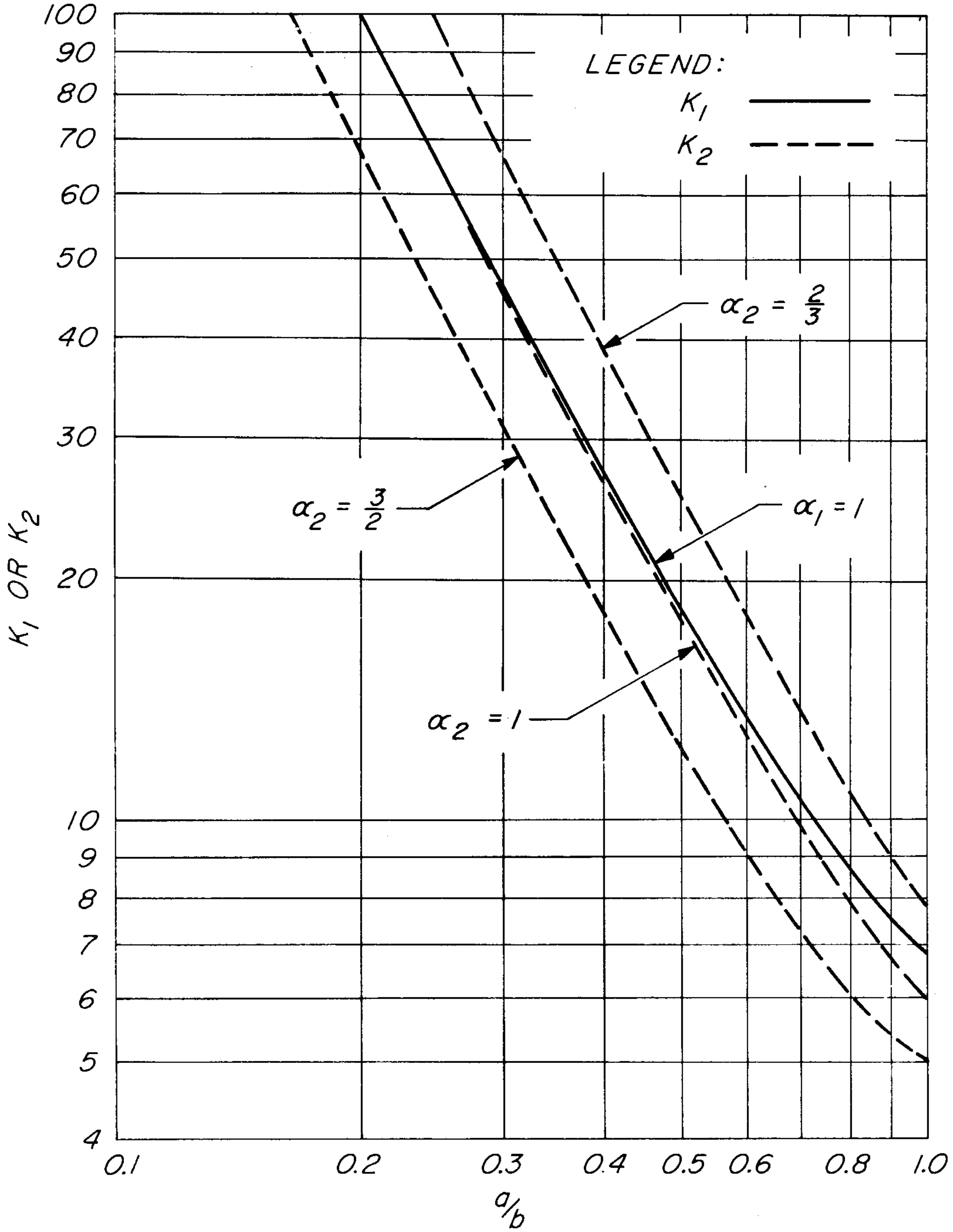
M 127 510

Figure 92.--Buckling coefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



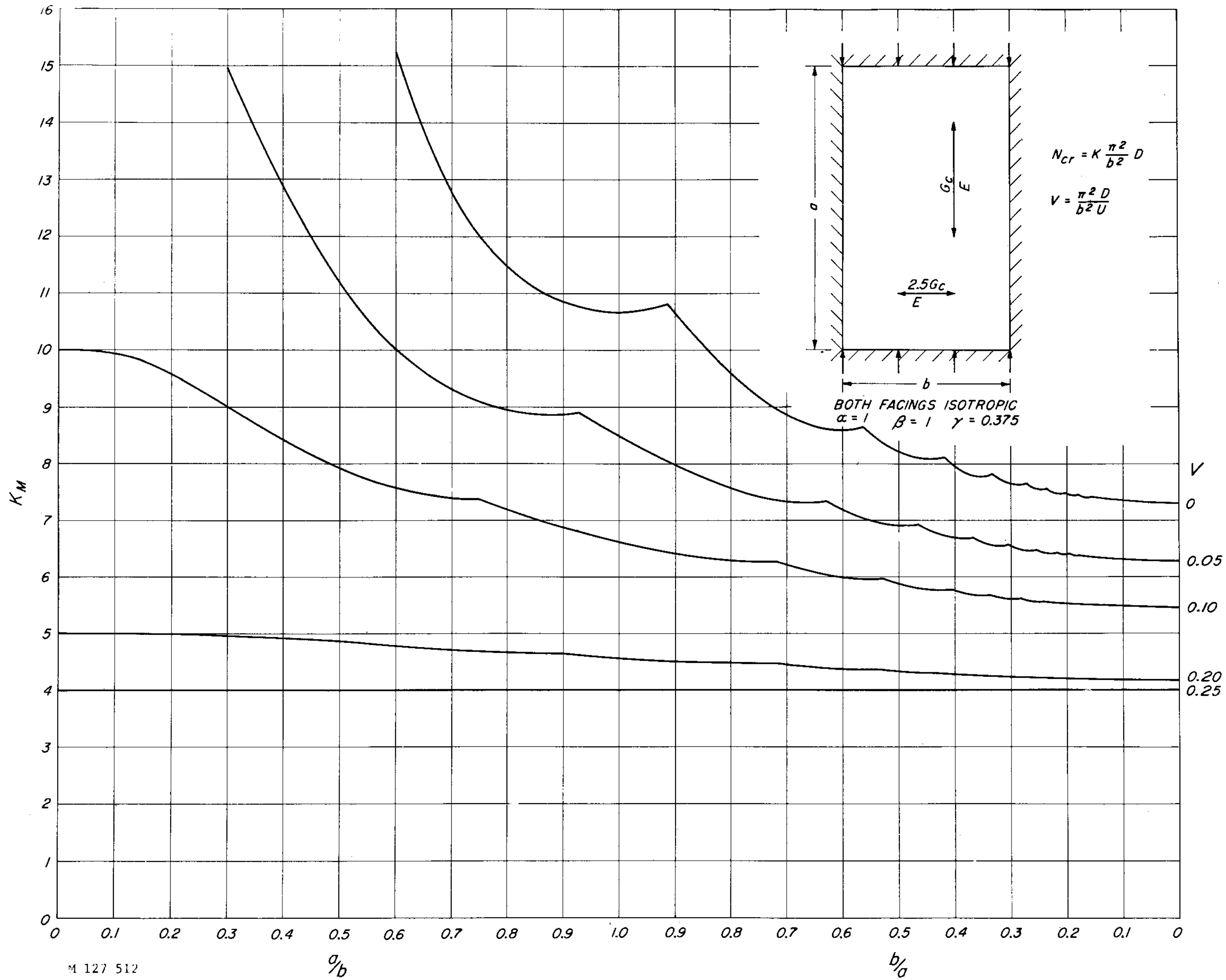
M 127 511

Figure 93.--Bucklingcoefficients for sandwich panels in edge compression. Loaded edges clamped, other edges simply supported.



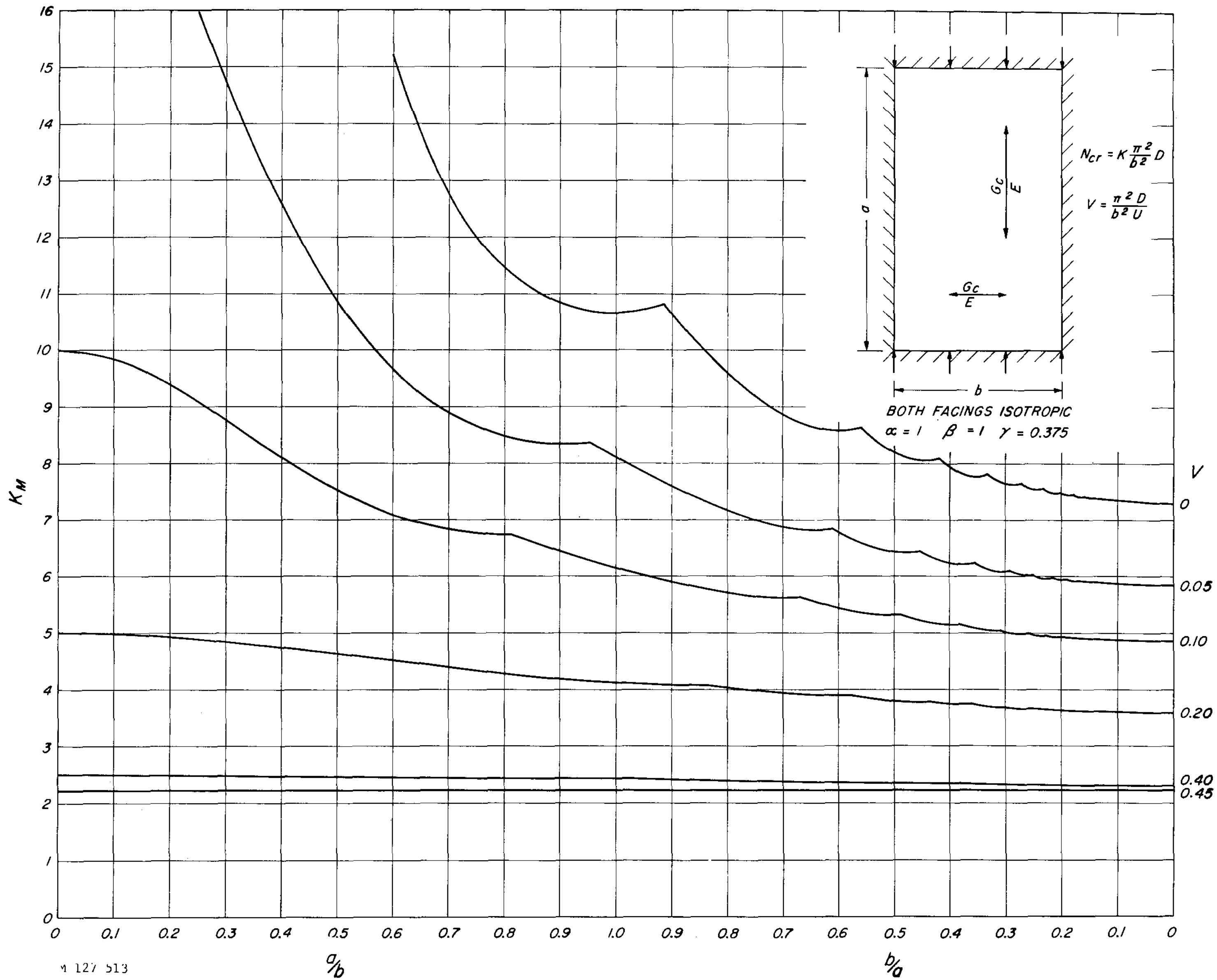
M 127 845

Figure 94.--Values of $\underline{K_1}$ and $\underline{K_2}$ (n = 1), for sandwich panels with loaded edges clamped, other edges simply supported. $\beta_1 = 1$, $\lambda_1 = 3/8$. $\beta_2 = 0.6$, $\lambda_2 = 0.2$.



M 127 512

Figure 95.--Buckling coefficients for sandwich panels in edge compression. All edges clamped



M 127 513

Figure 96.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

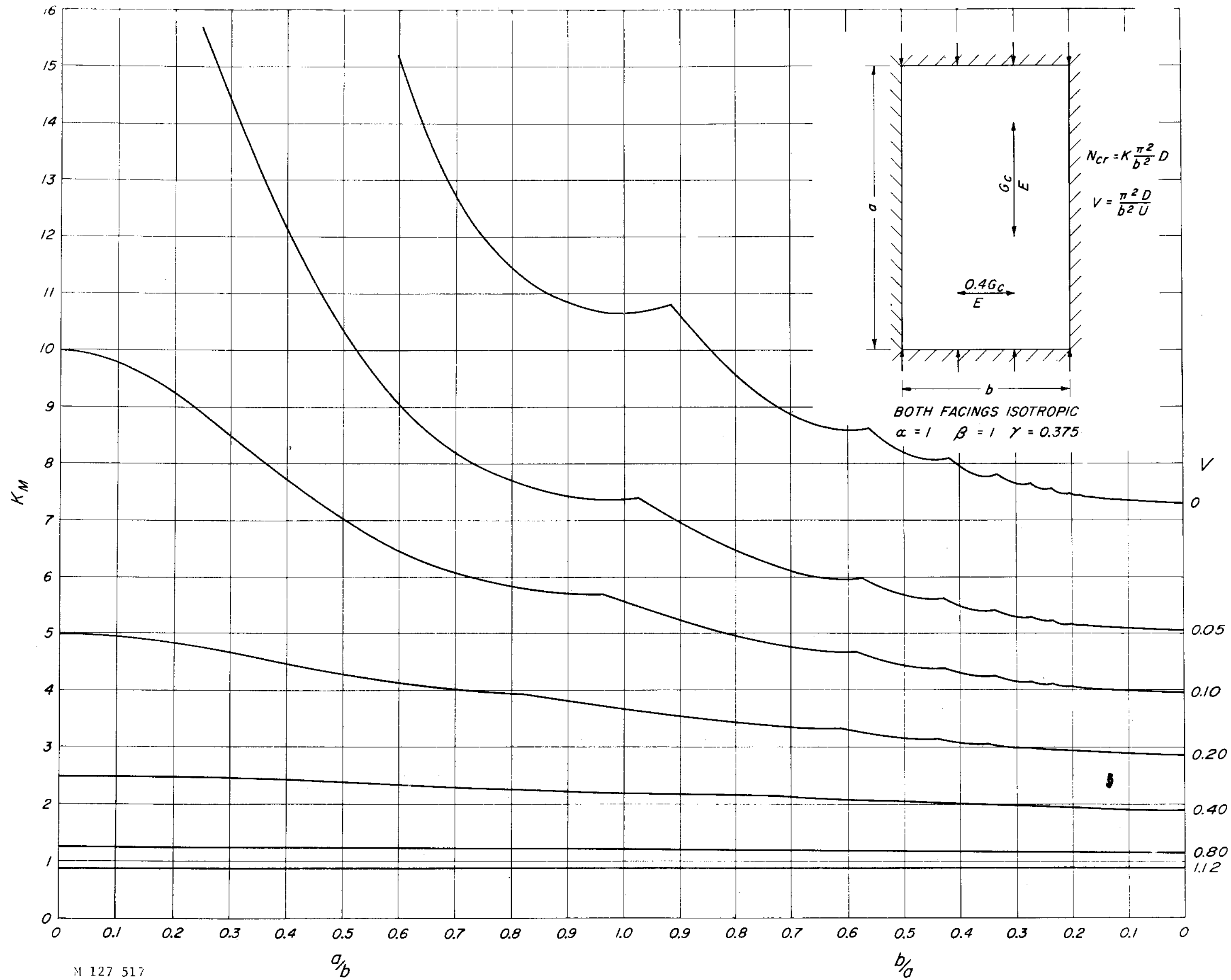


Figure 97.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

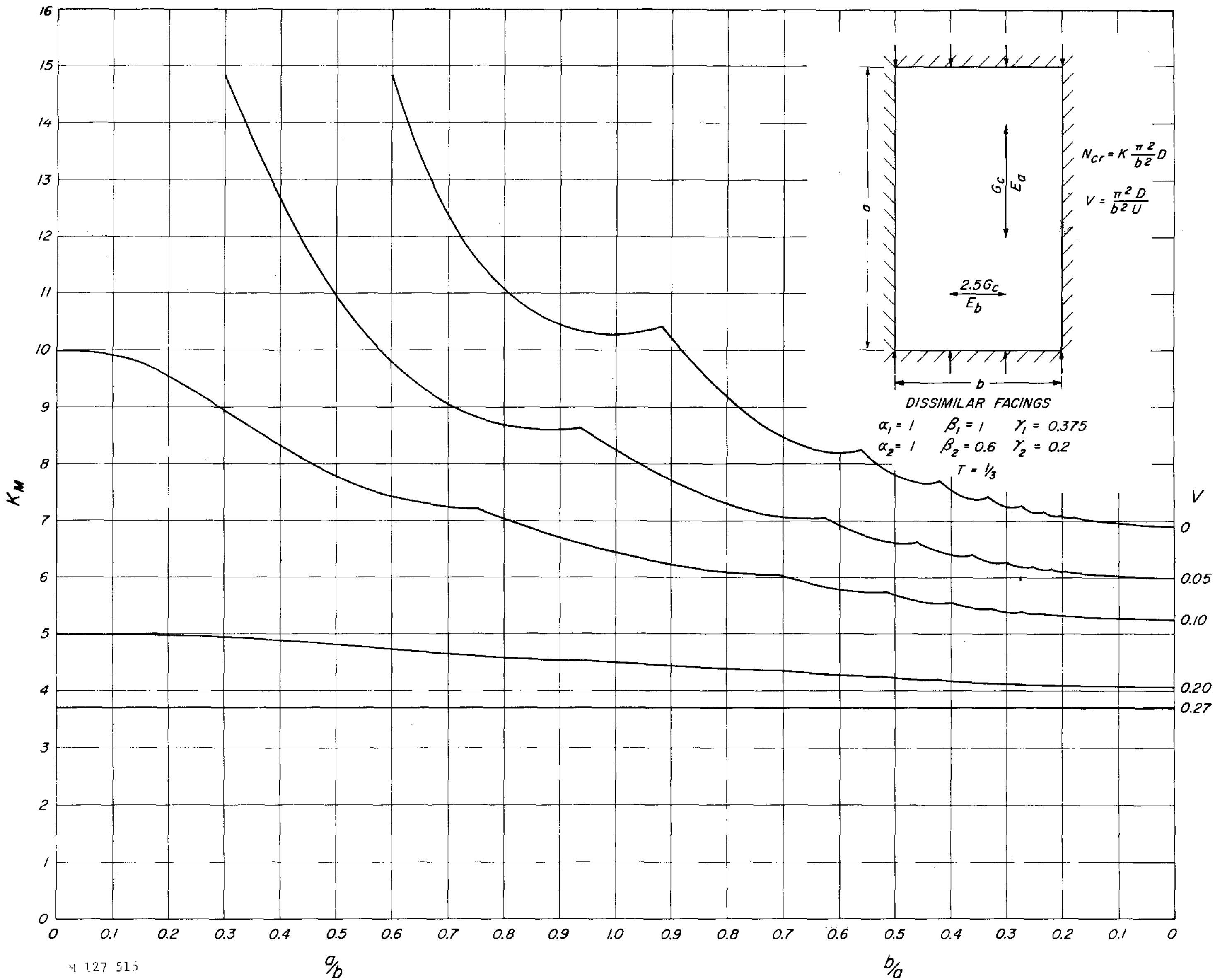
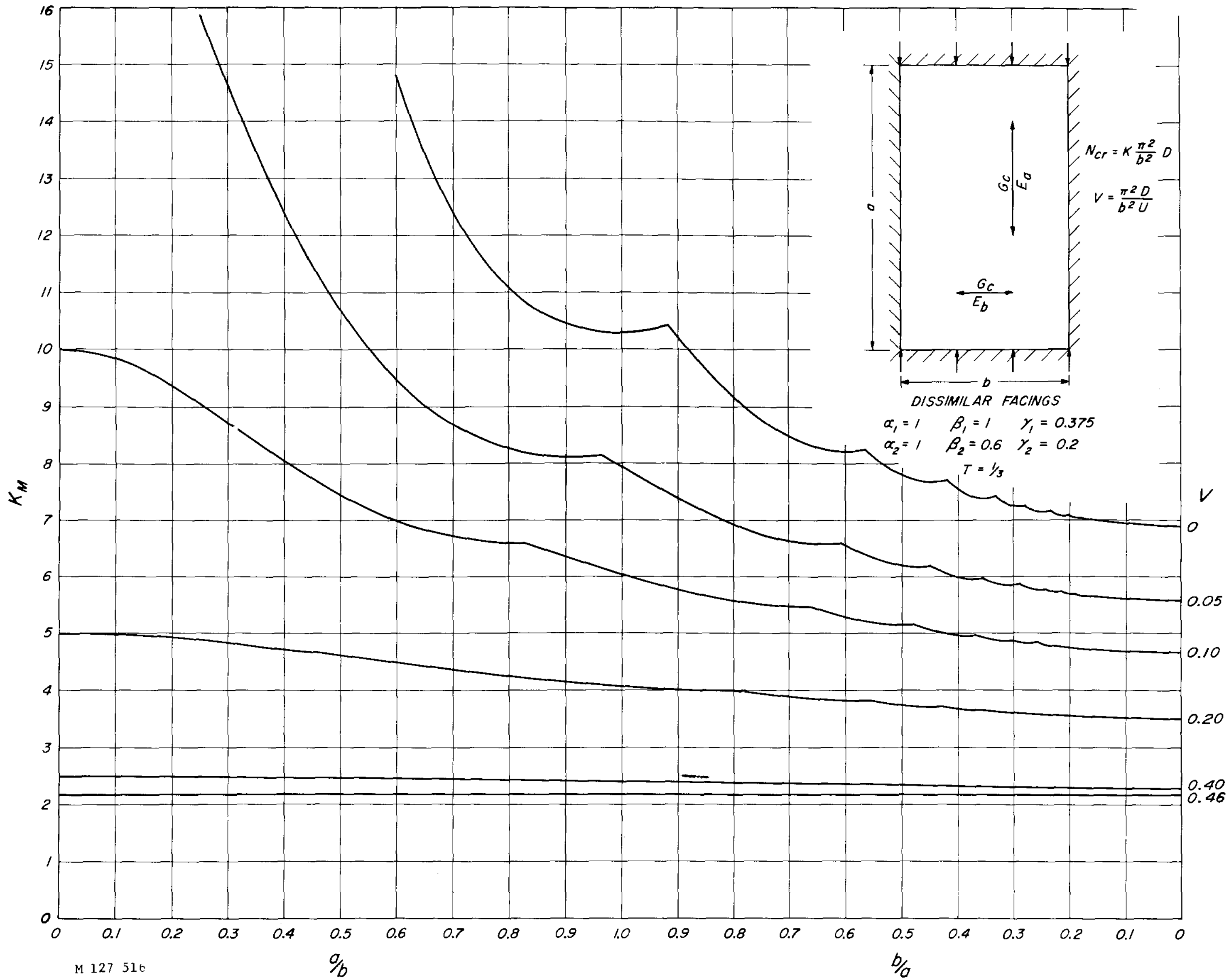


Figure 98.--Buckling coefficients for sandwich panels in edge compression All edges clamped.



M 127 516

Figure 99.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

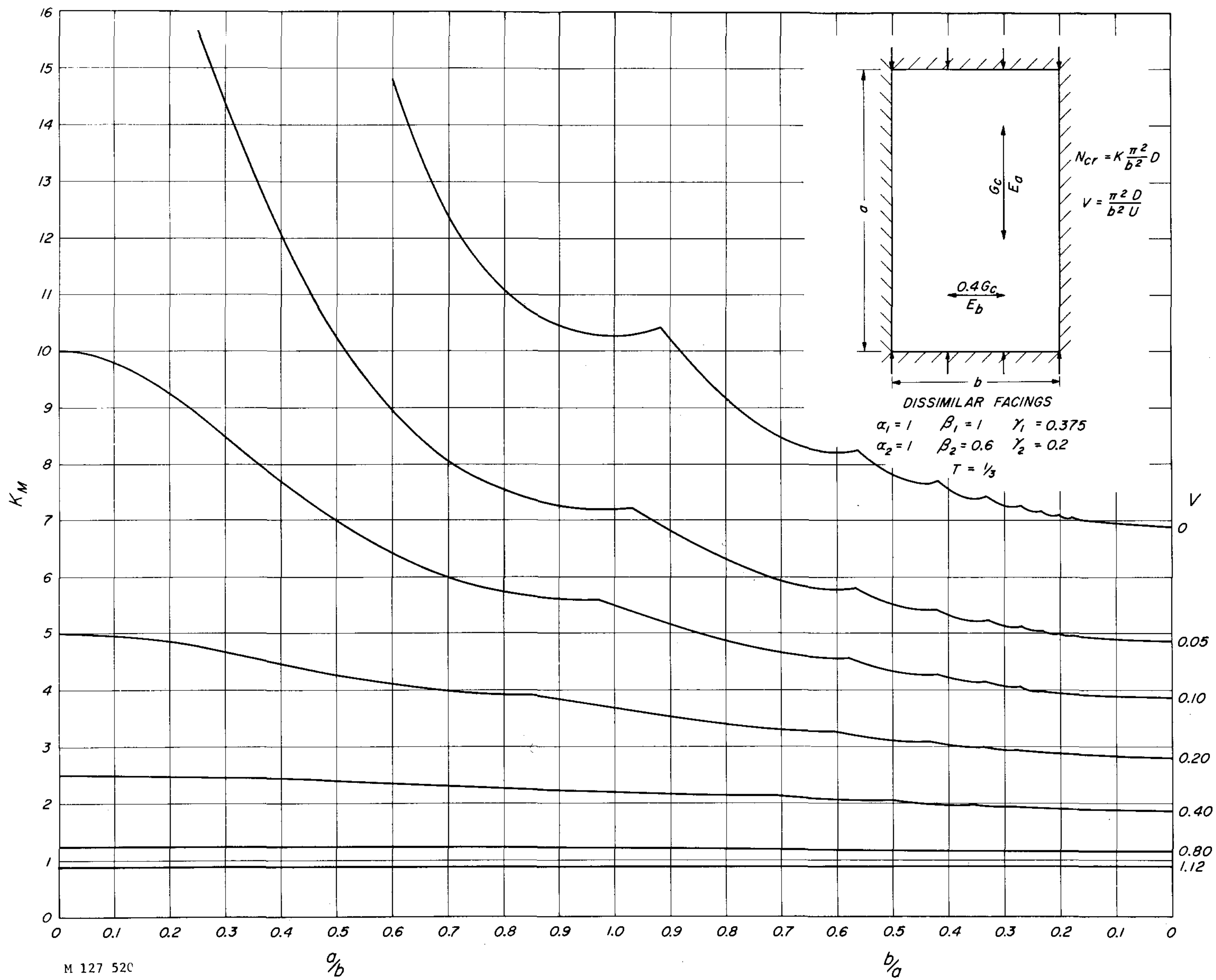


Figure 100.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

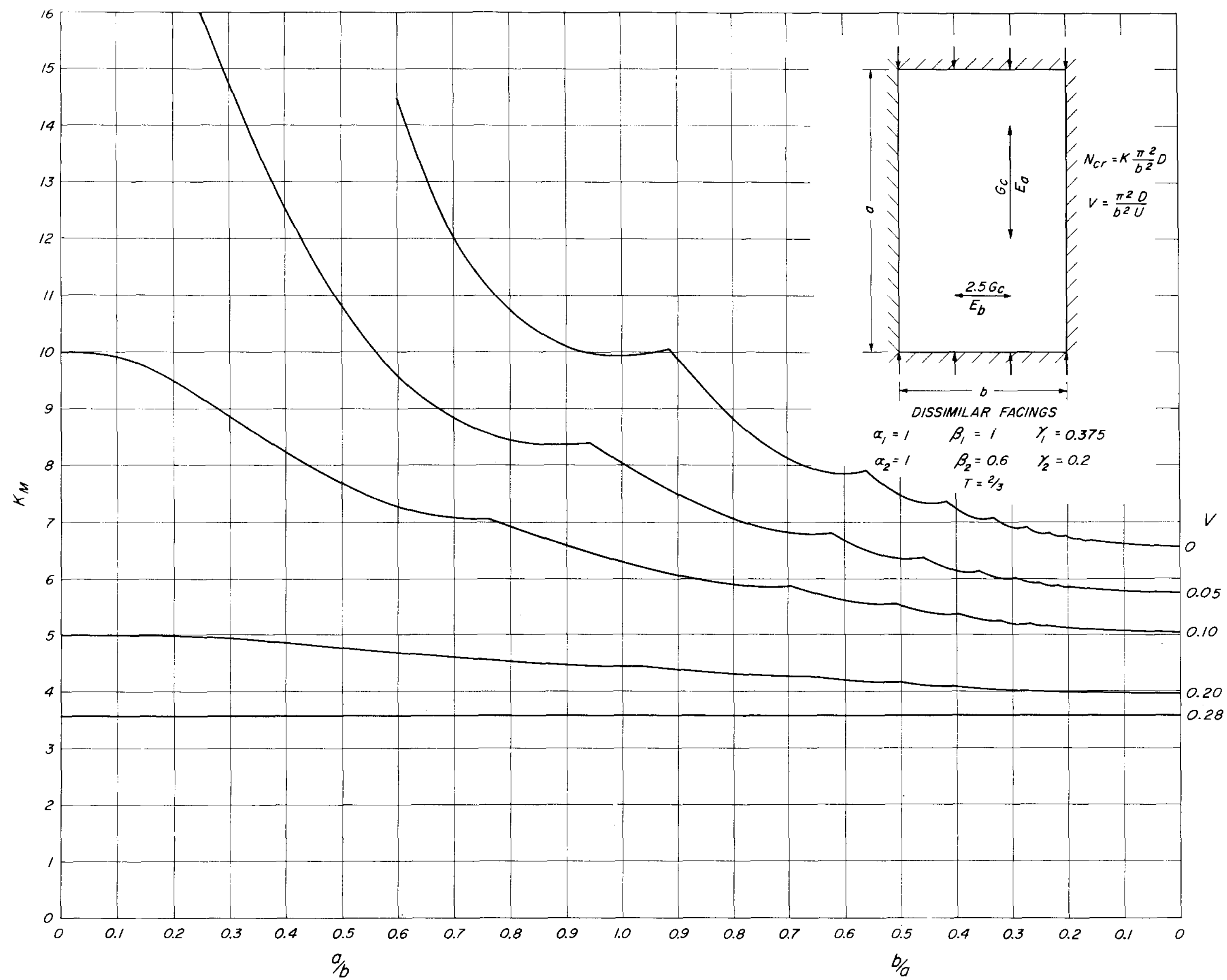
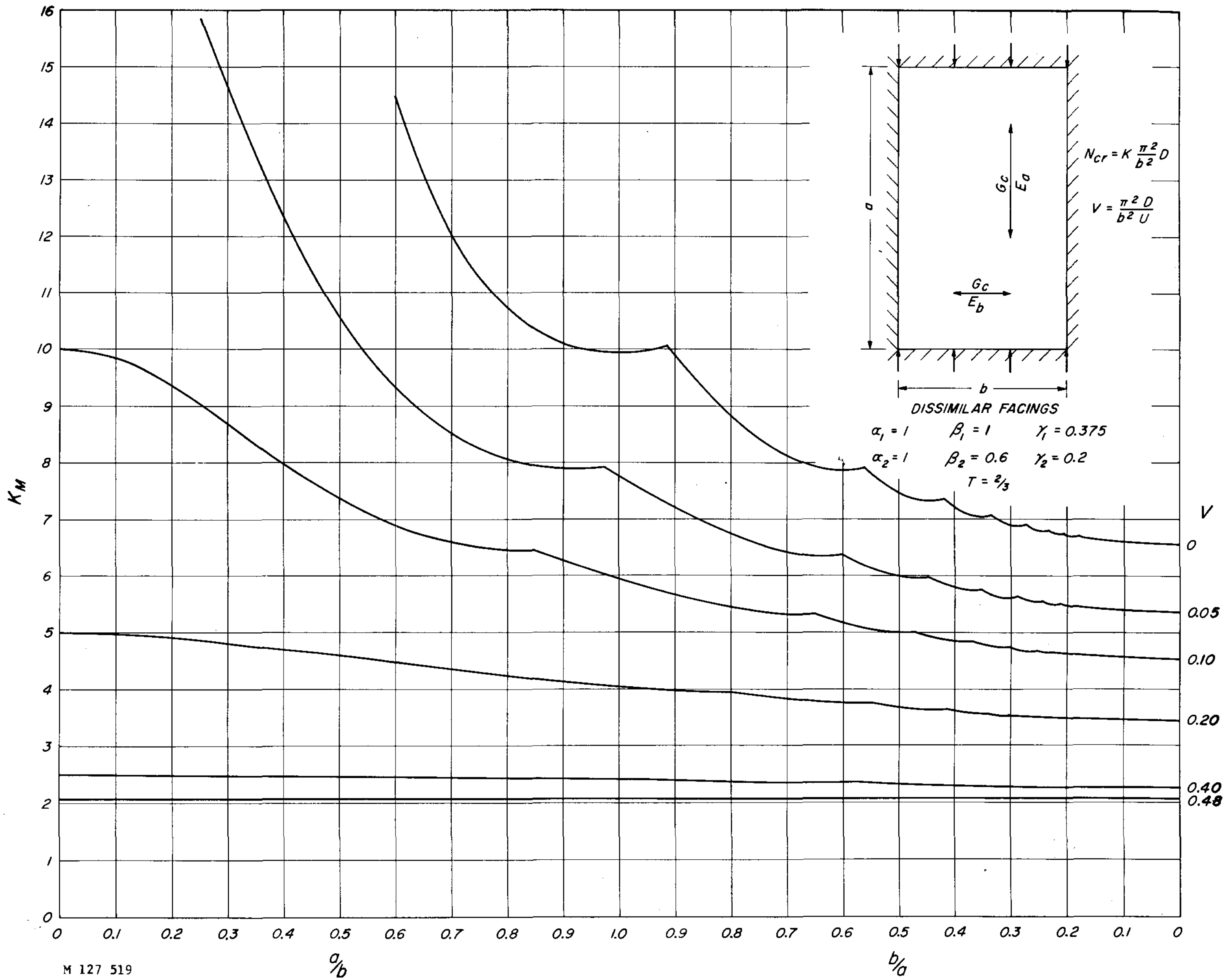
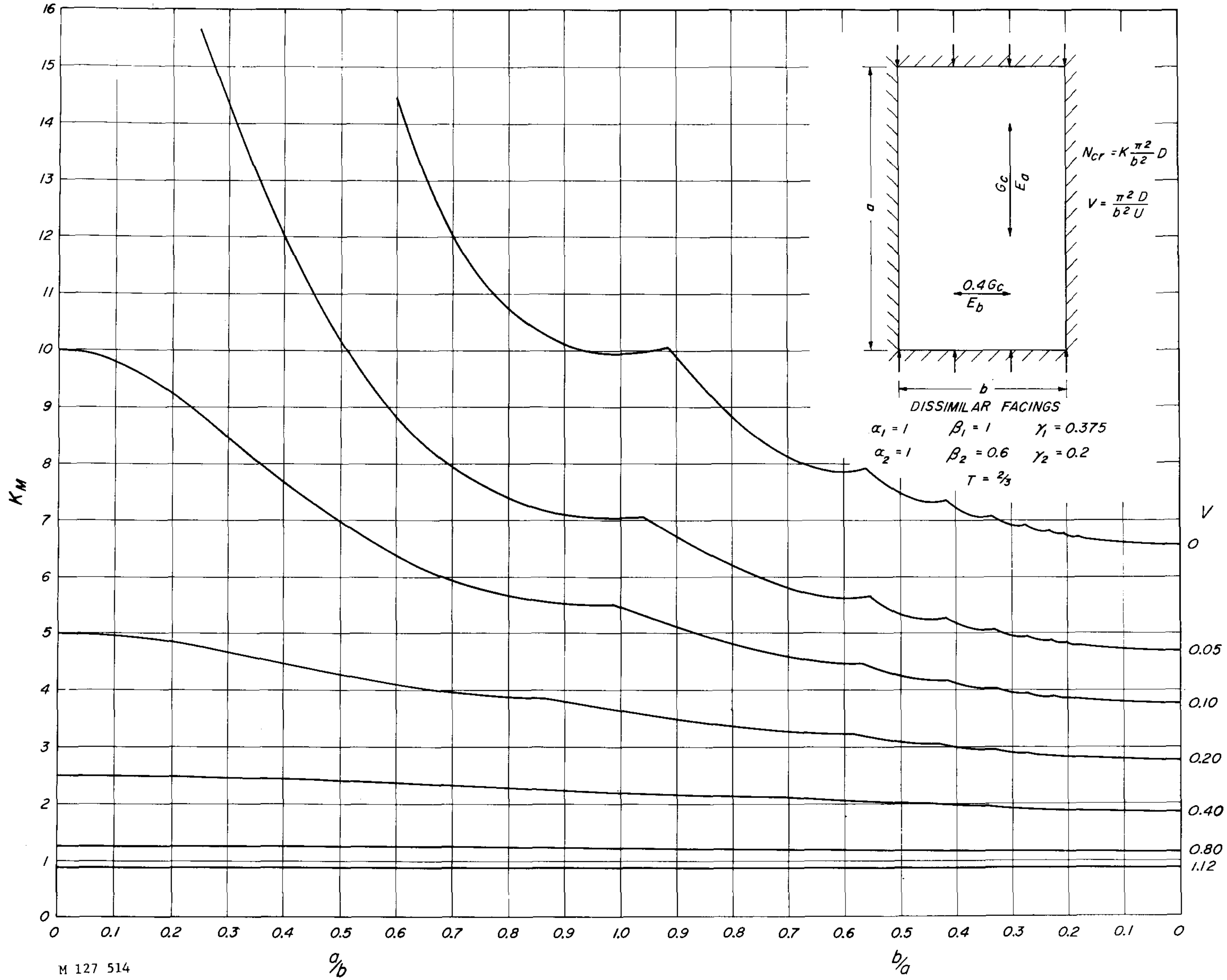


Figure 101.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 519

Figure 102.--Bucklingcoefficients for sandwich panels in edge compression. All edges clamped.



M 127 514

Figure 103.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

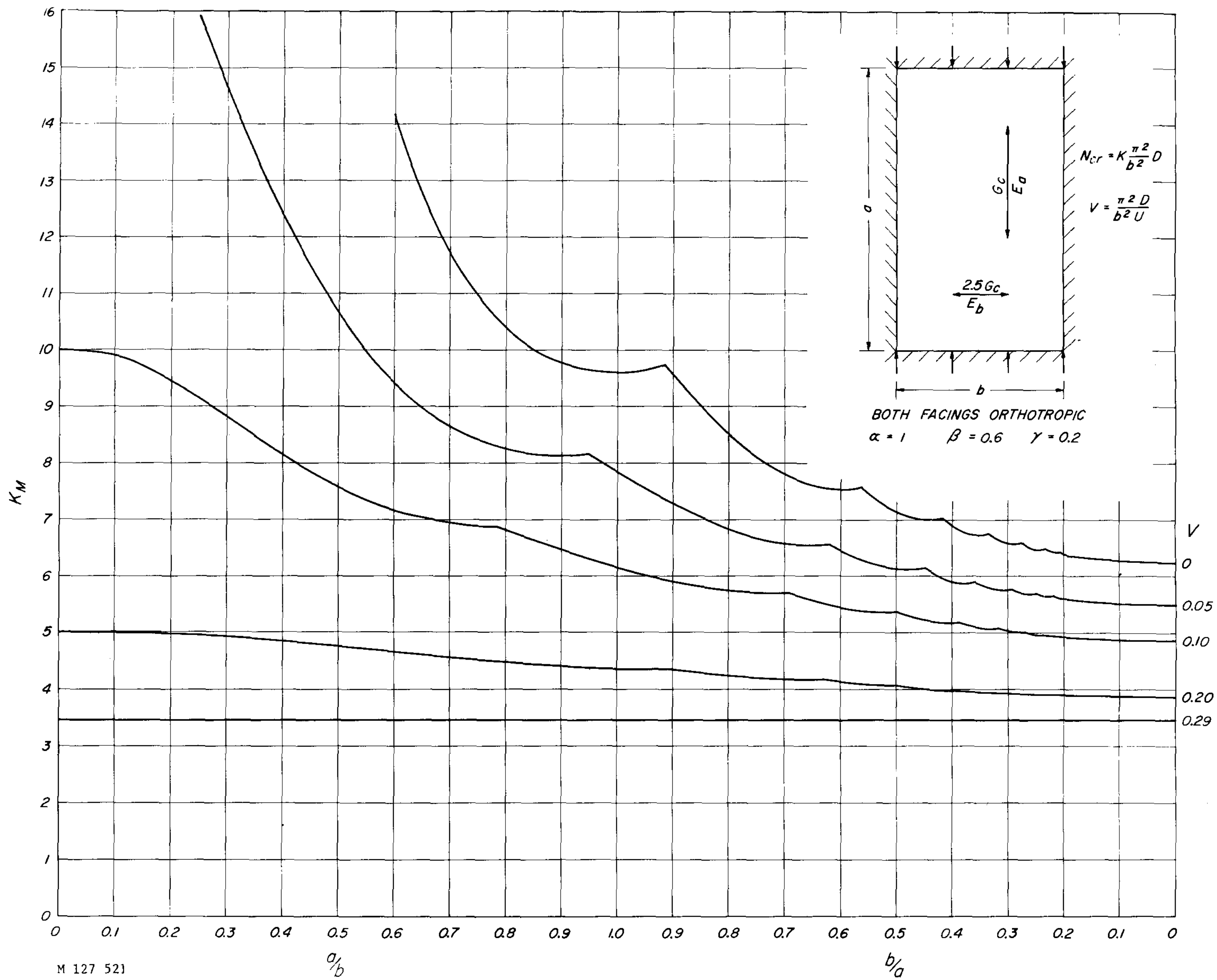


Figure 104.--Buckling coefficients for sandwich panels in edge compression. All edges clamped,

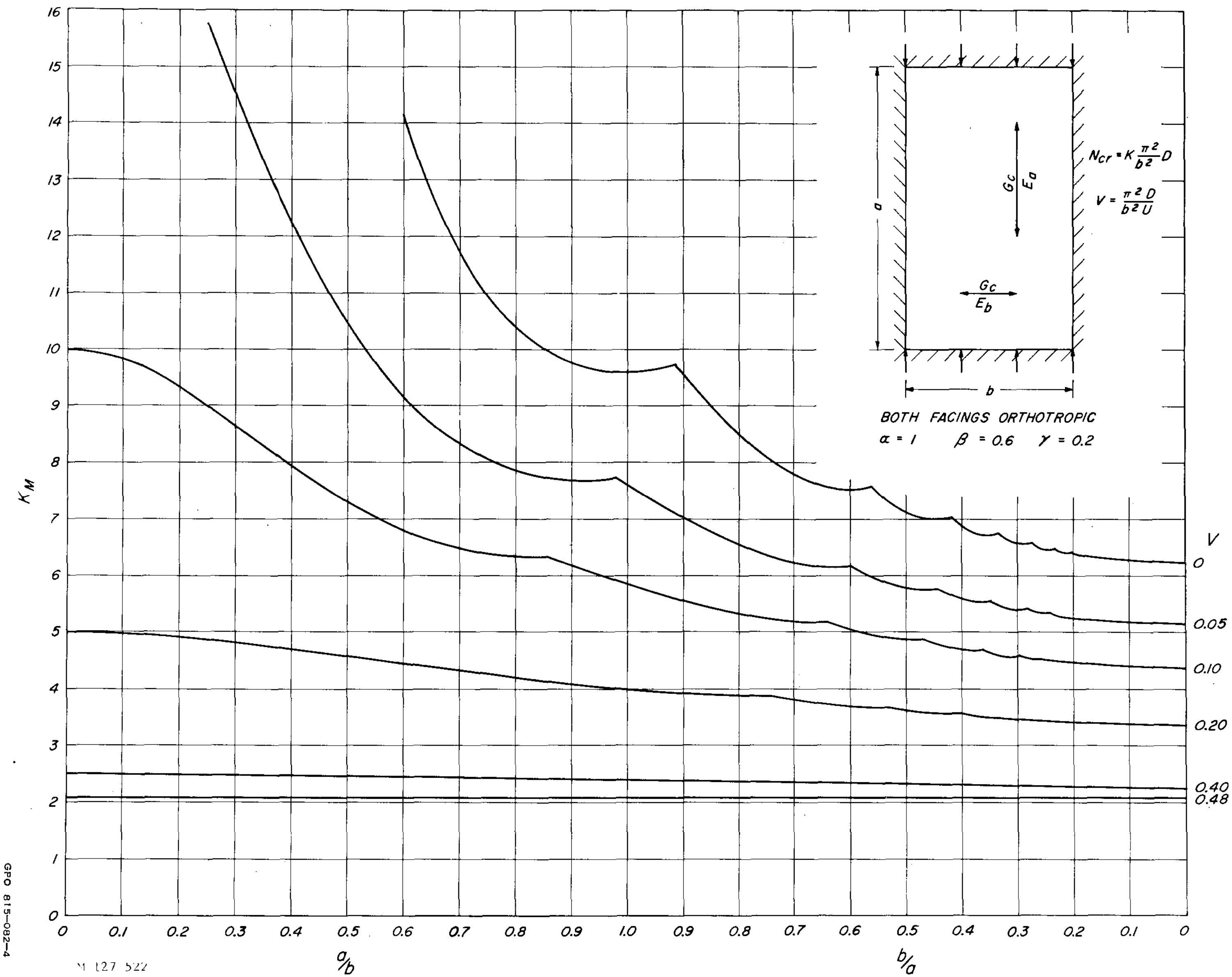


Figure 105.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

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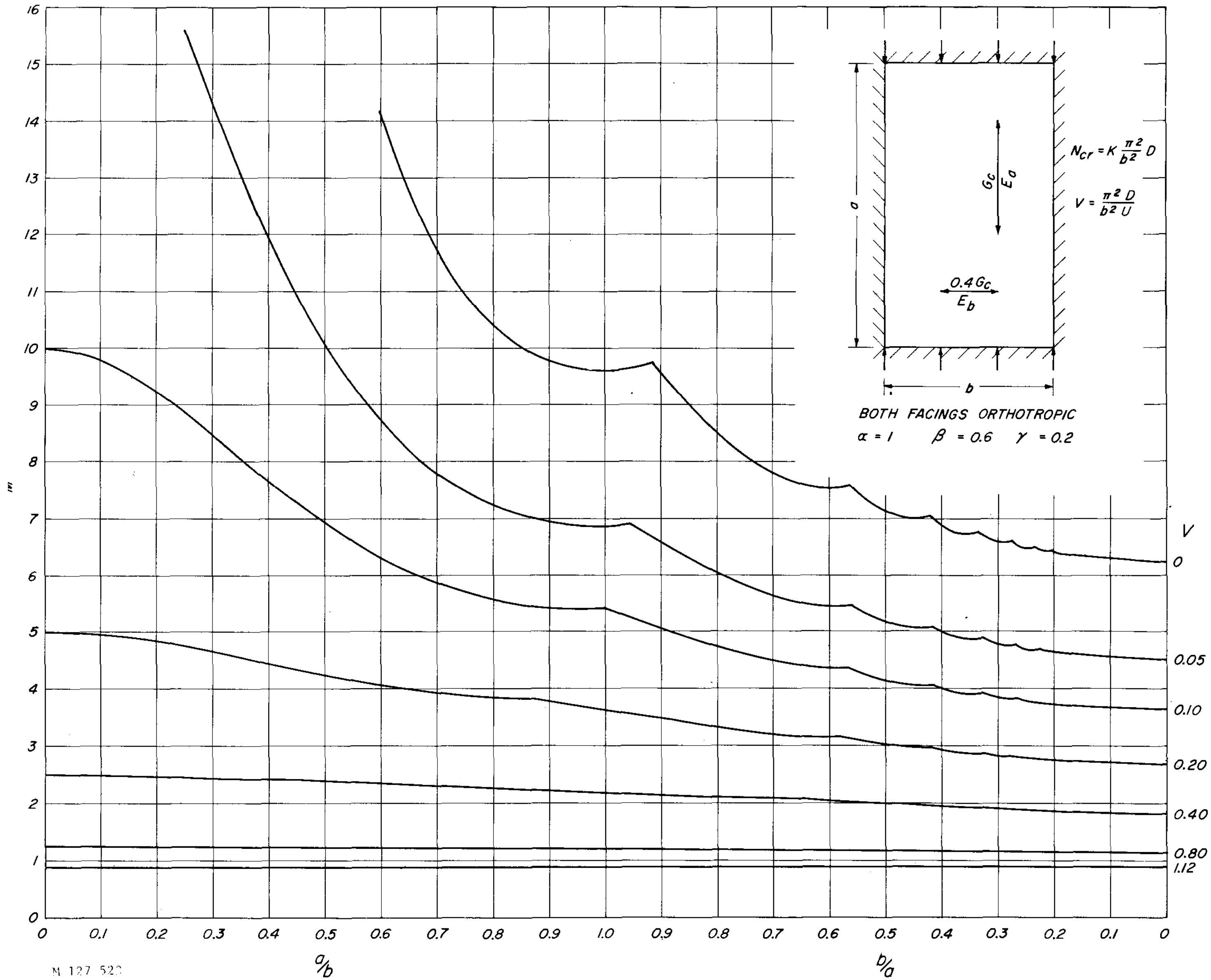
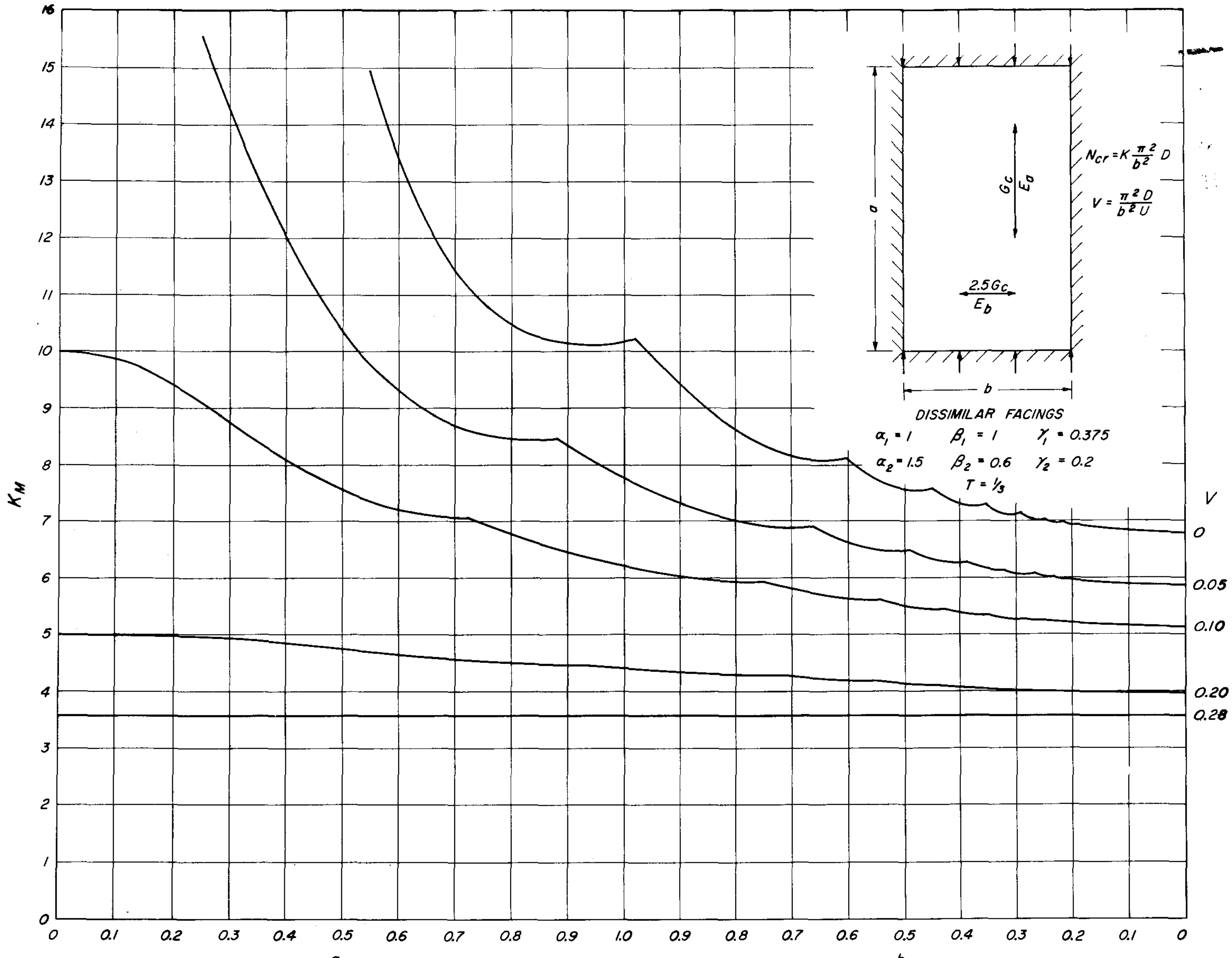


M 127 522

Figure 106.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 524

Figure 107.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

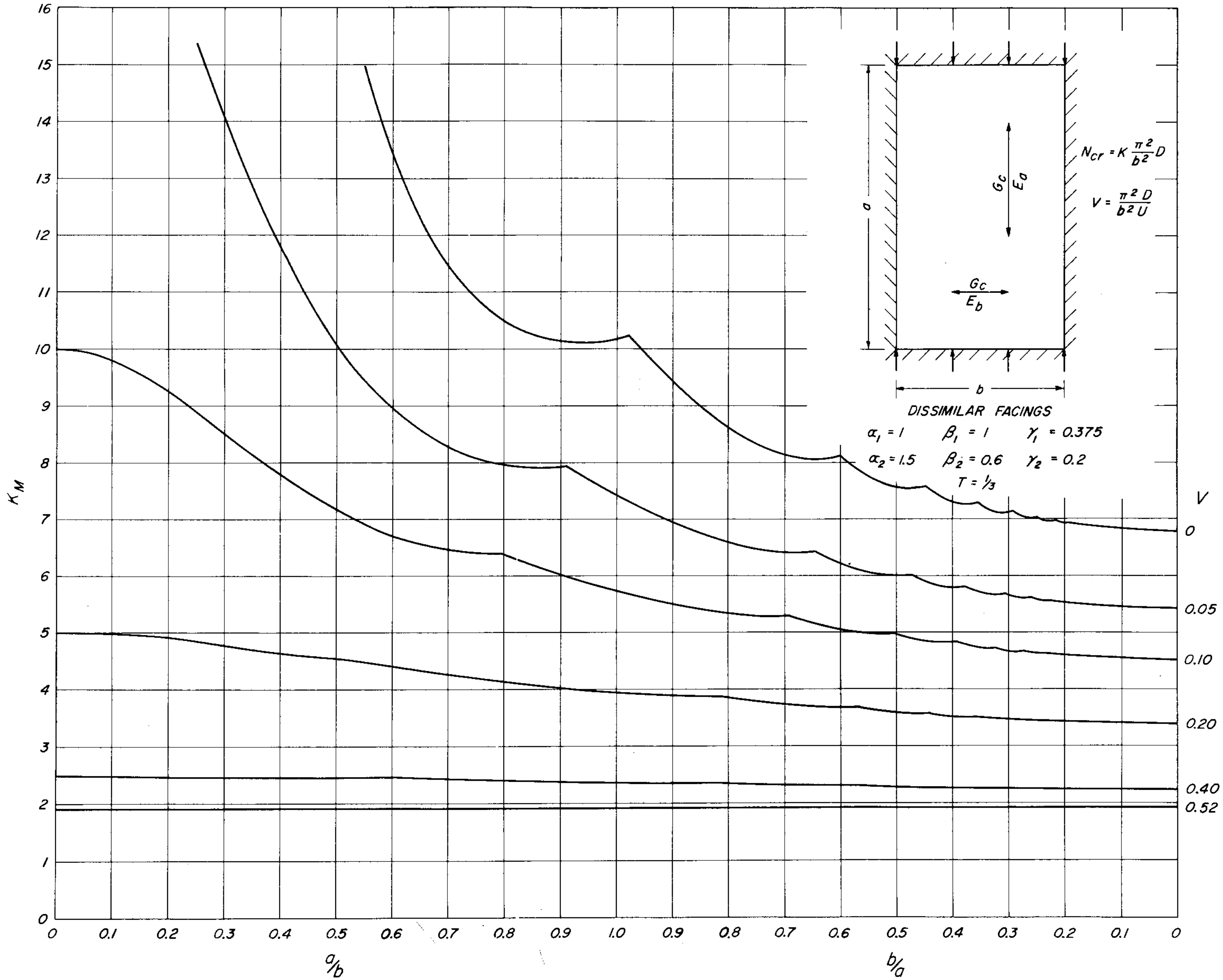
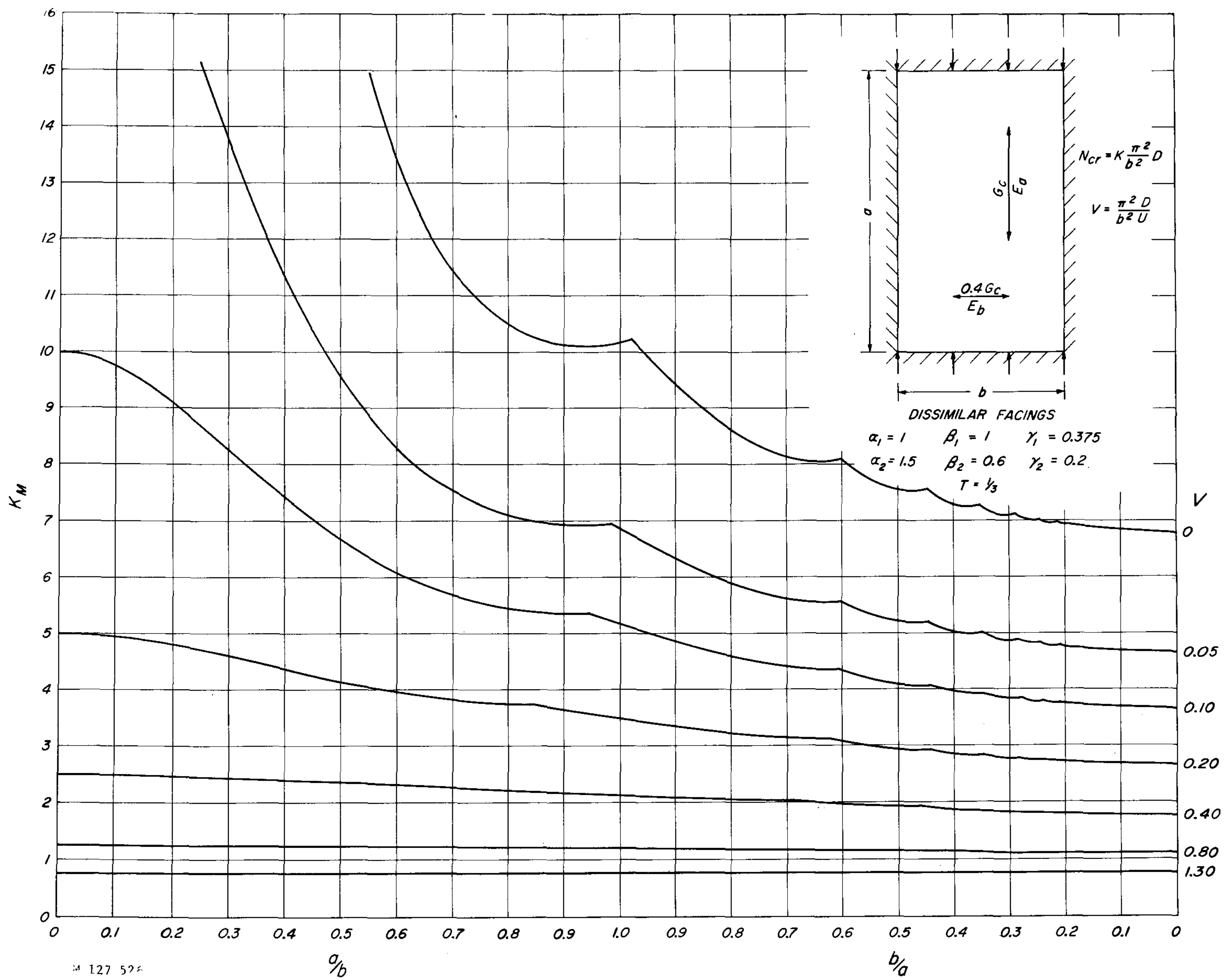
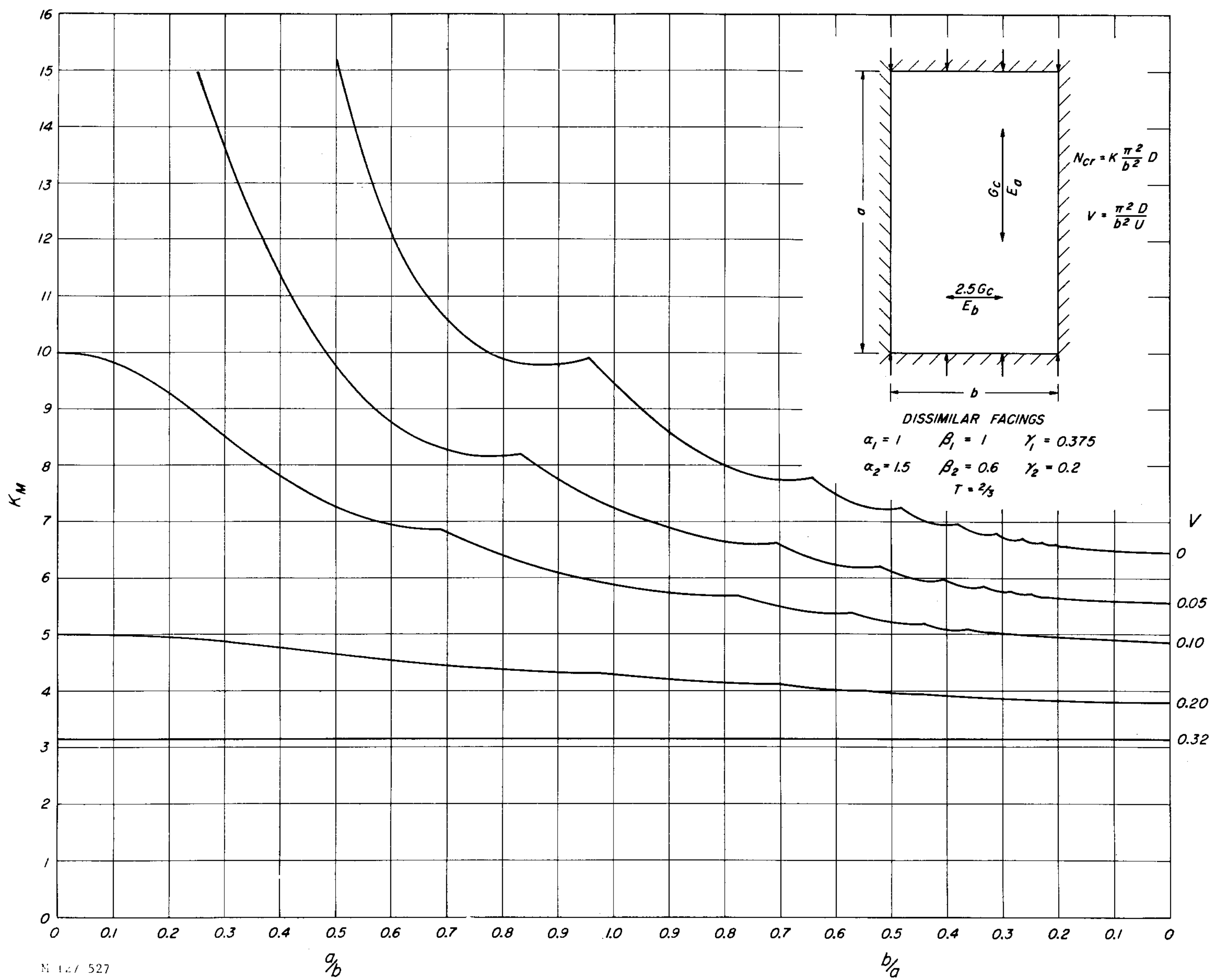


Figure 108.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



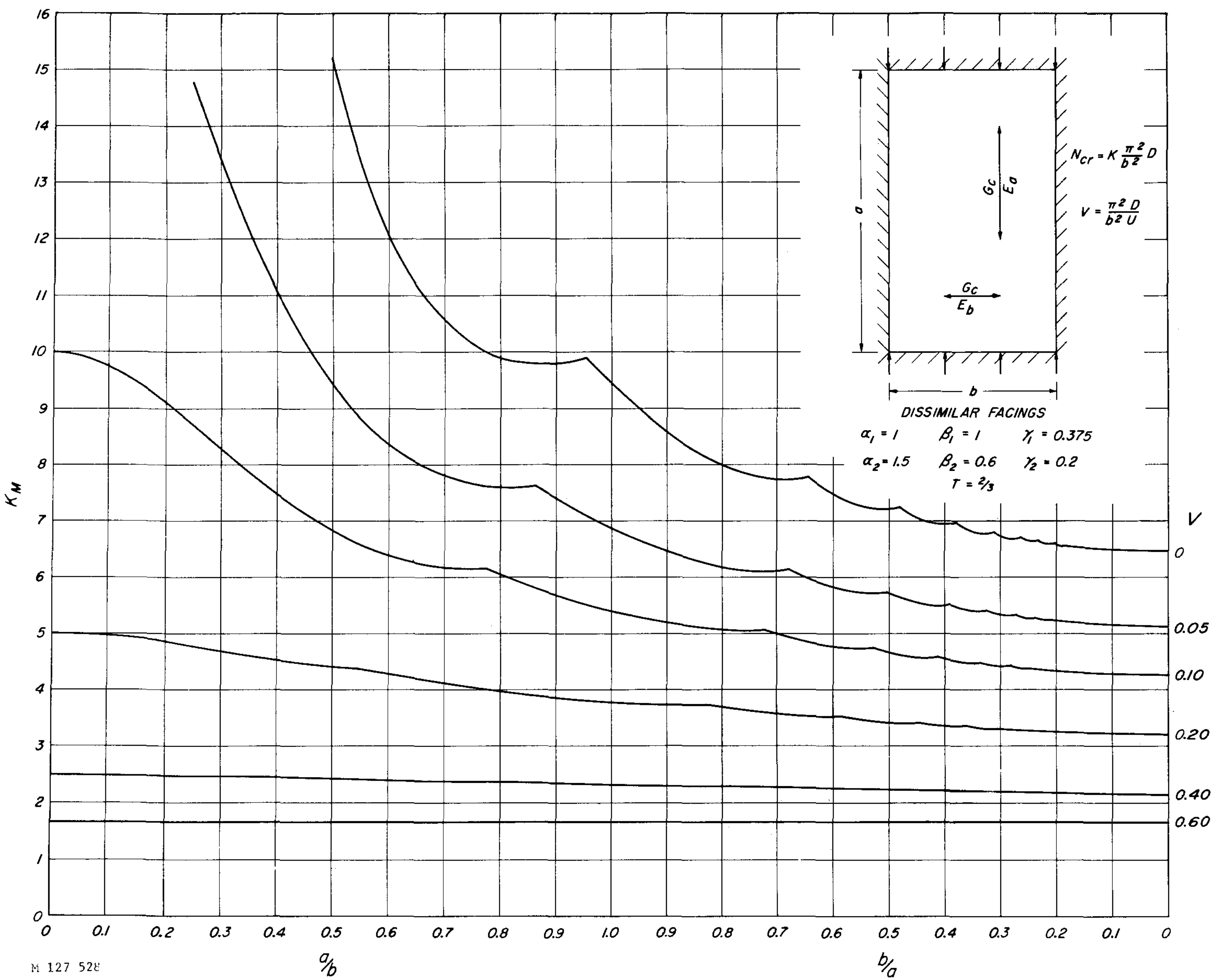
M 127 52?

Figure 109.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 527

Figure 110.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 528

Figure 111.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

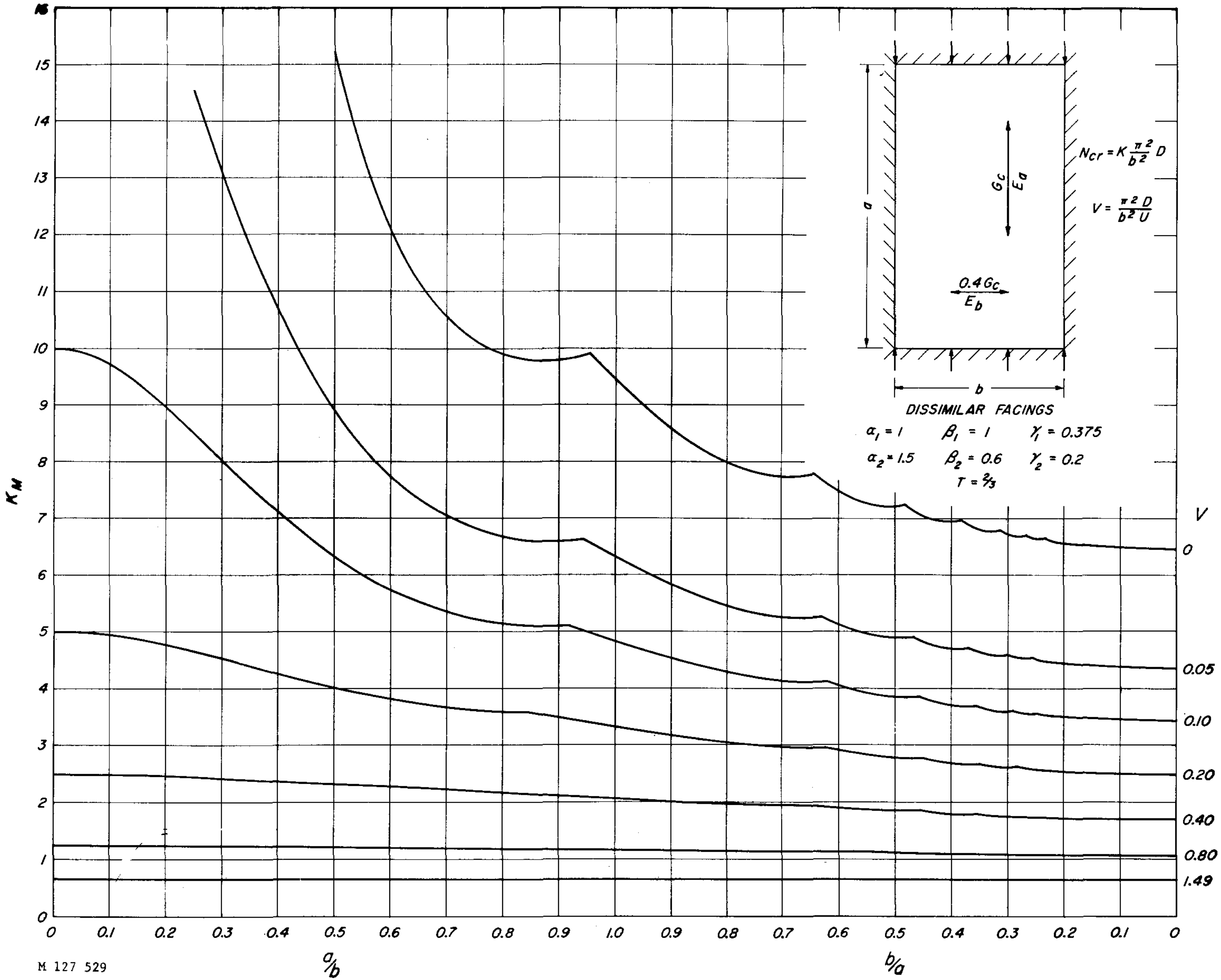
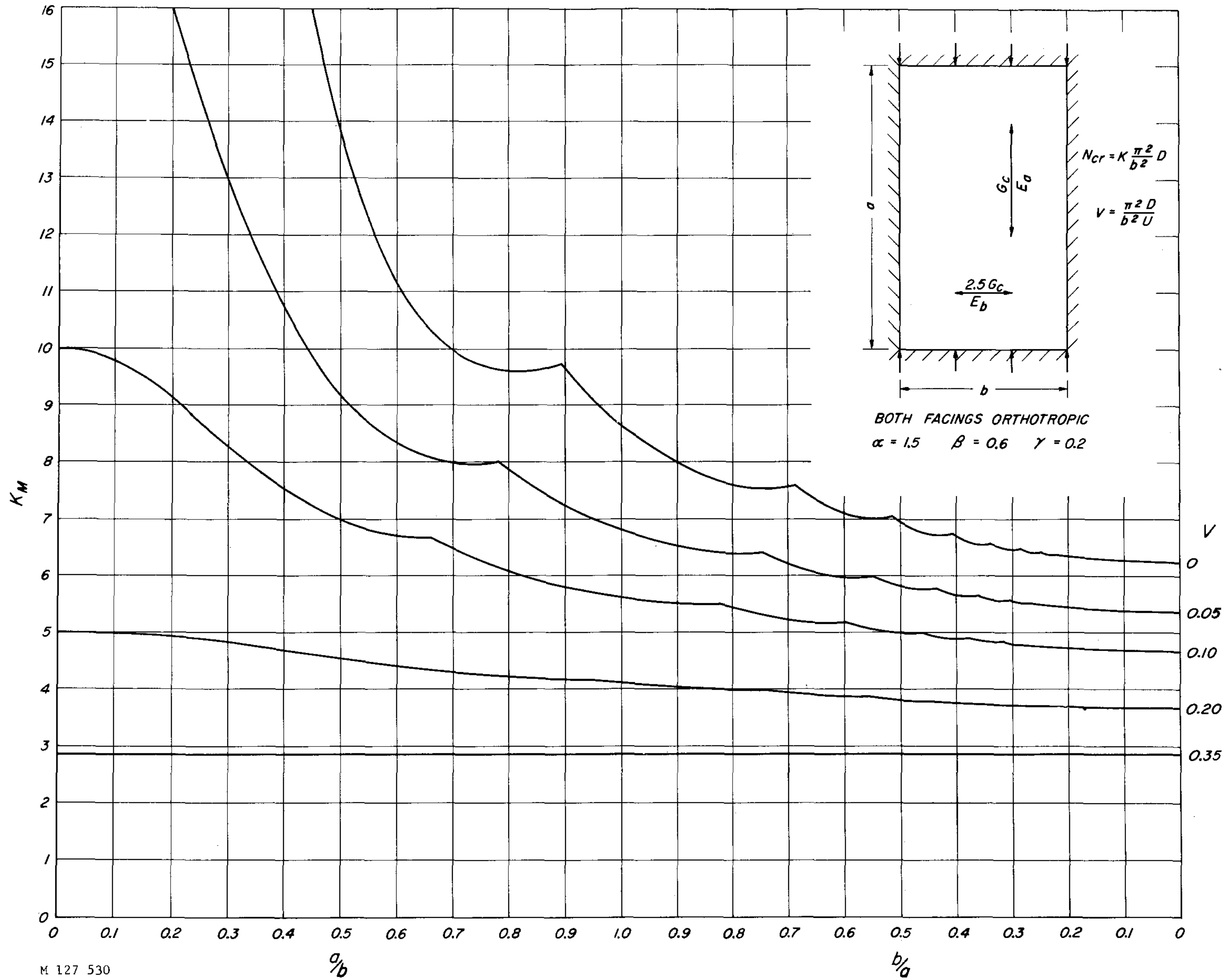
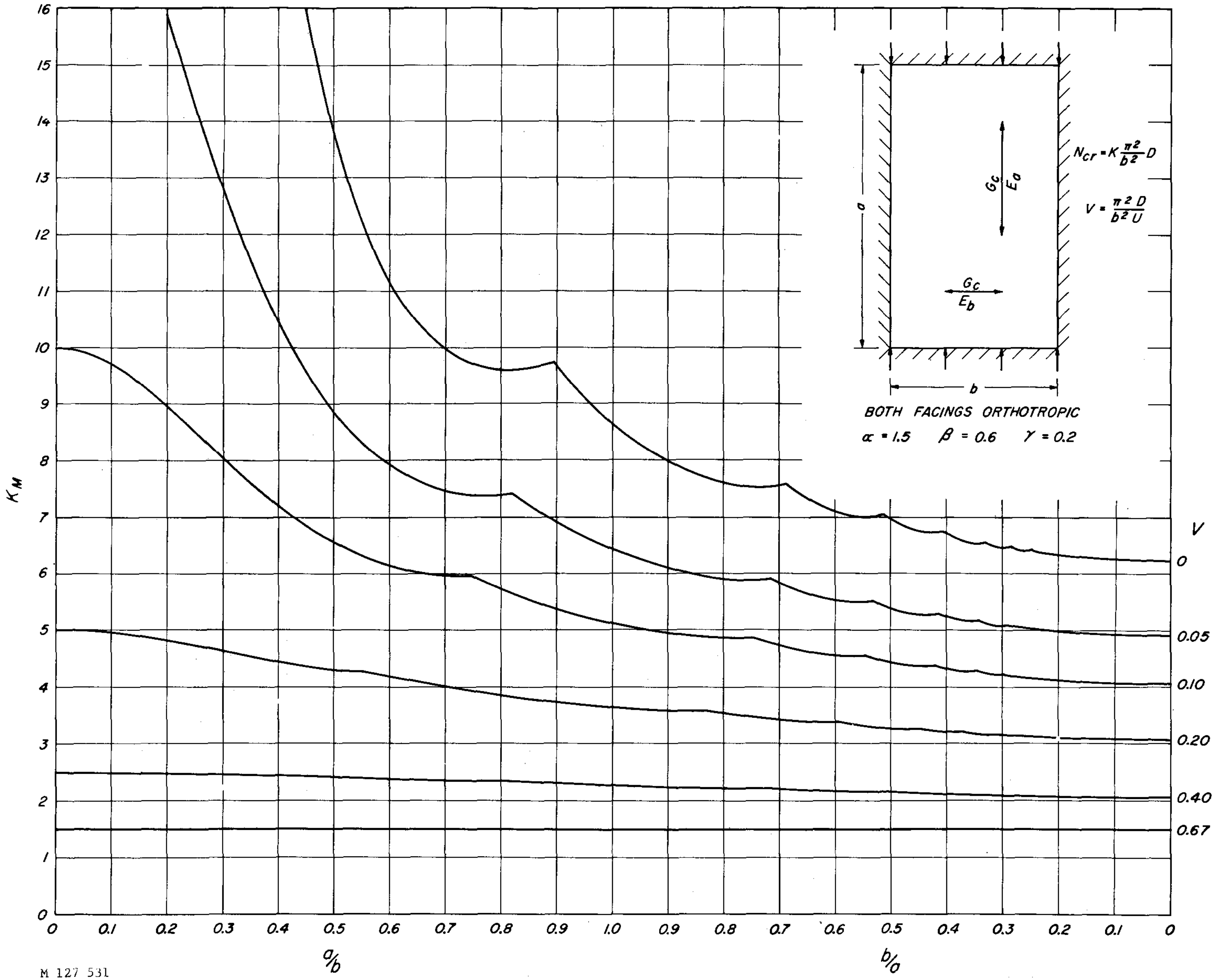


Figure 112.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 530

Figure 113.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 531

Figure 114.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

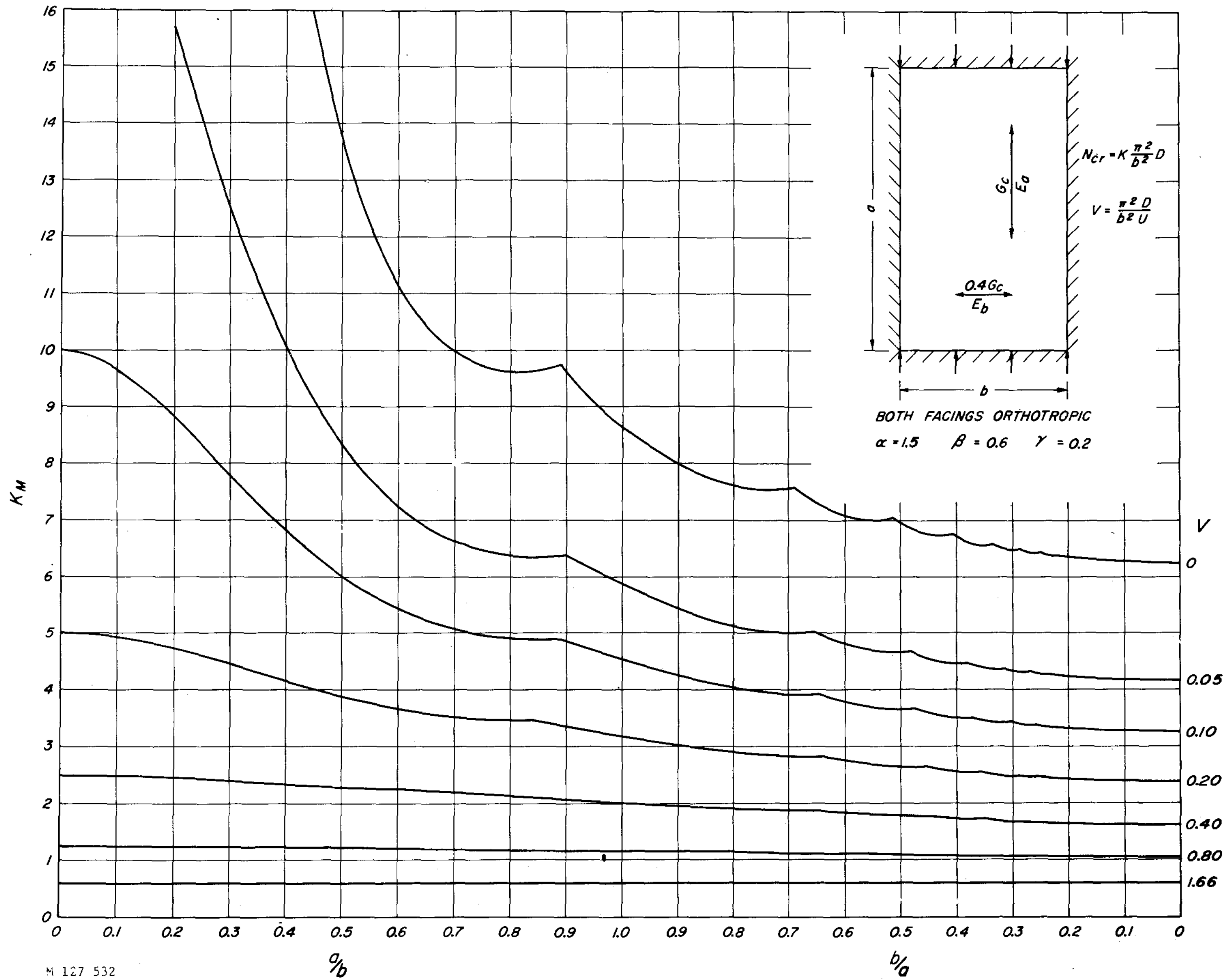
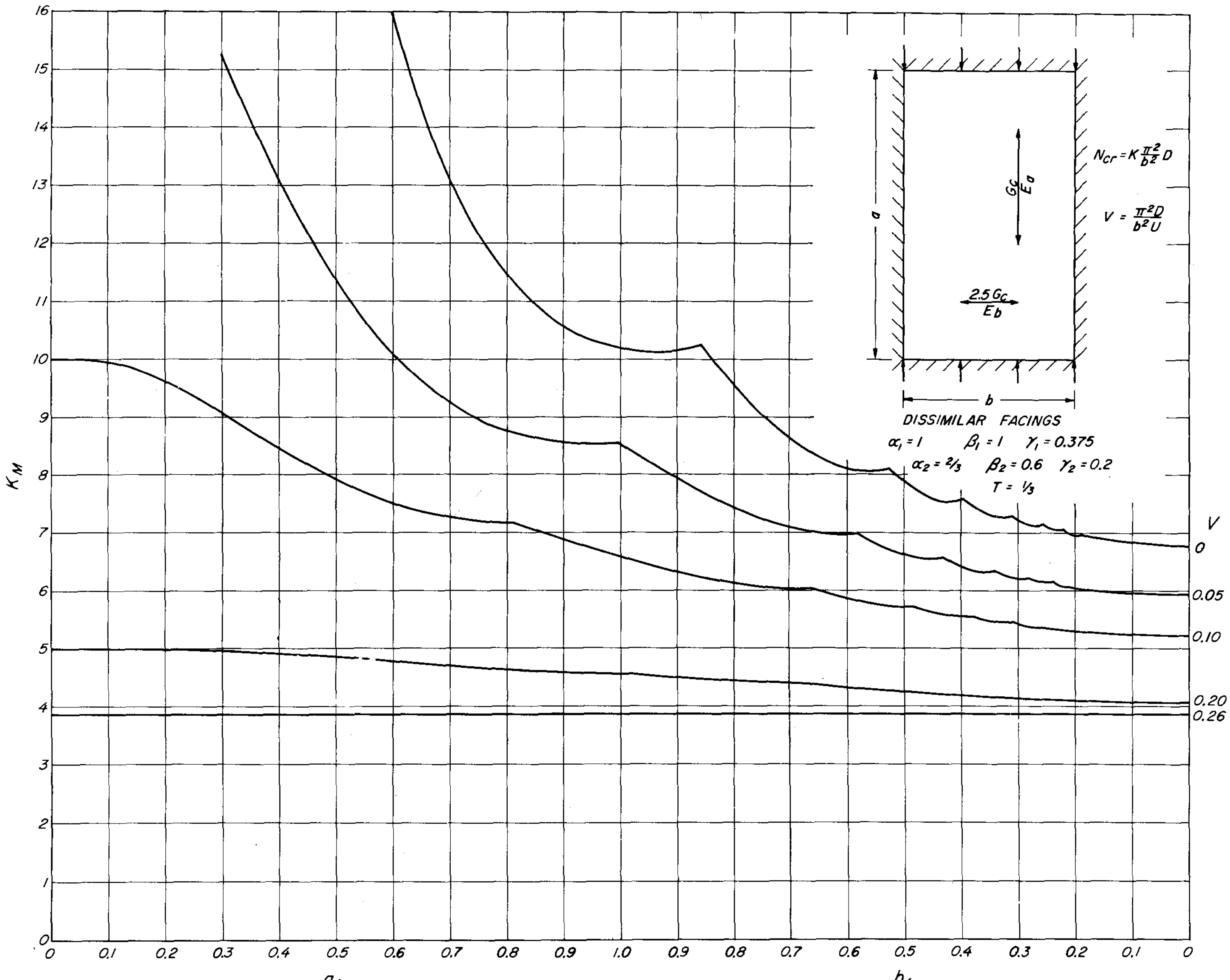
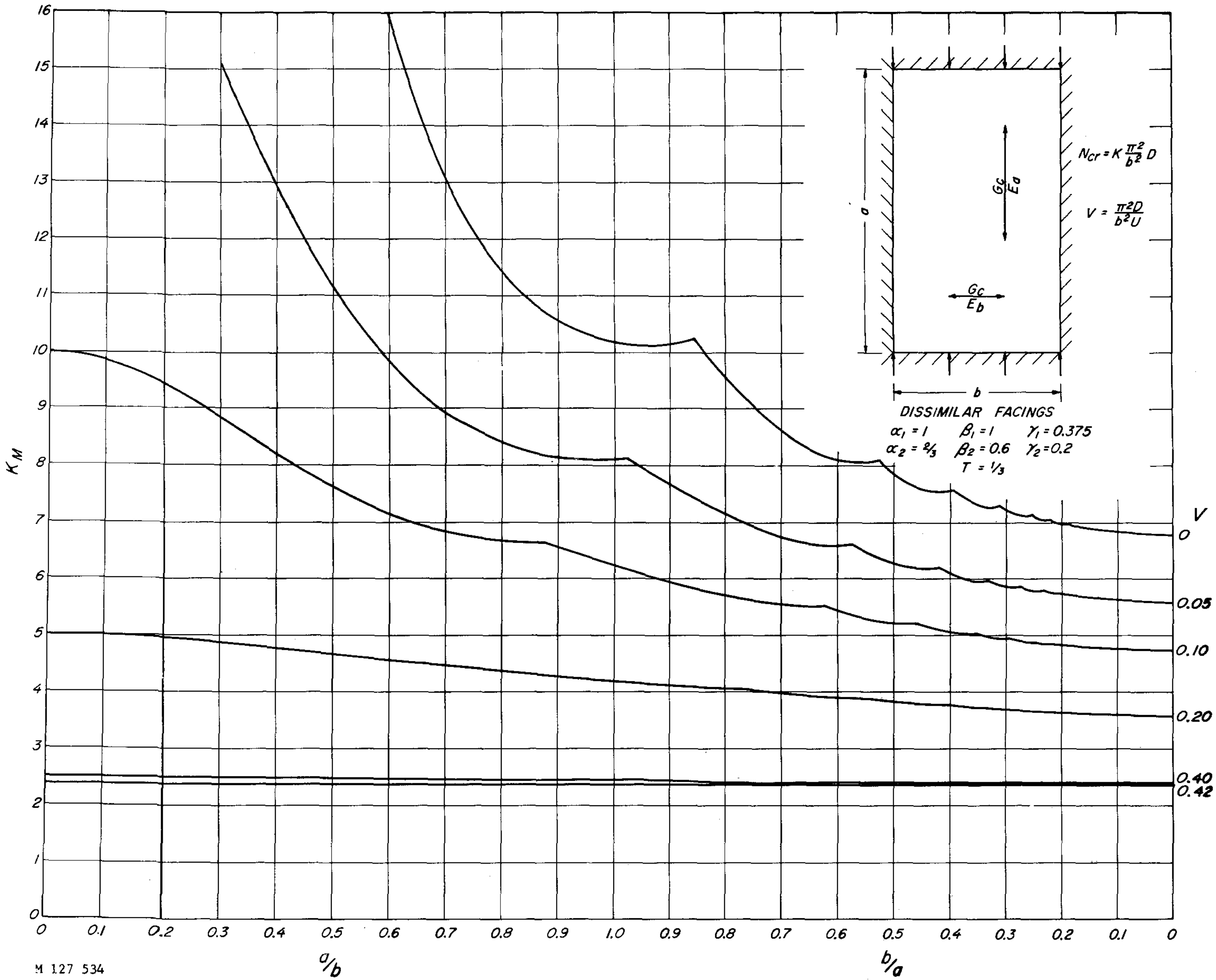


Figure 115.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



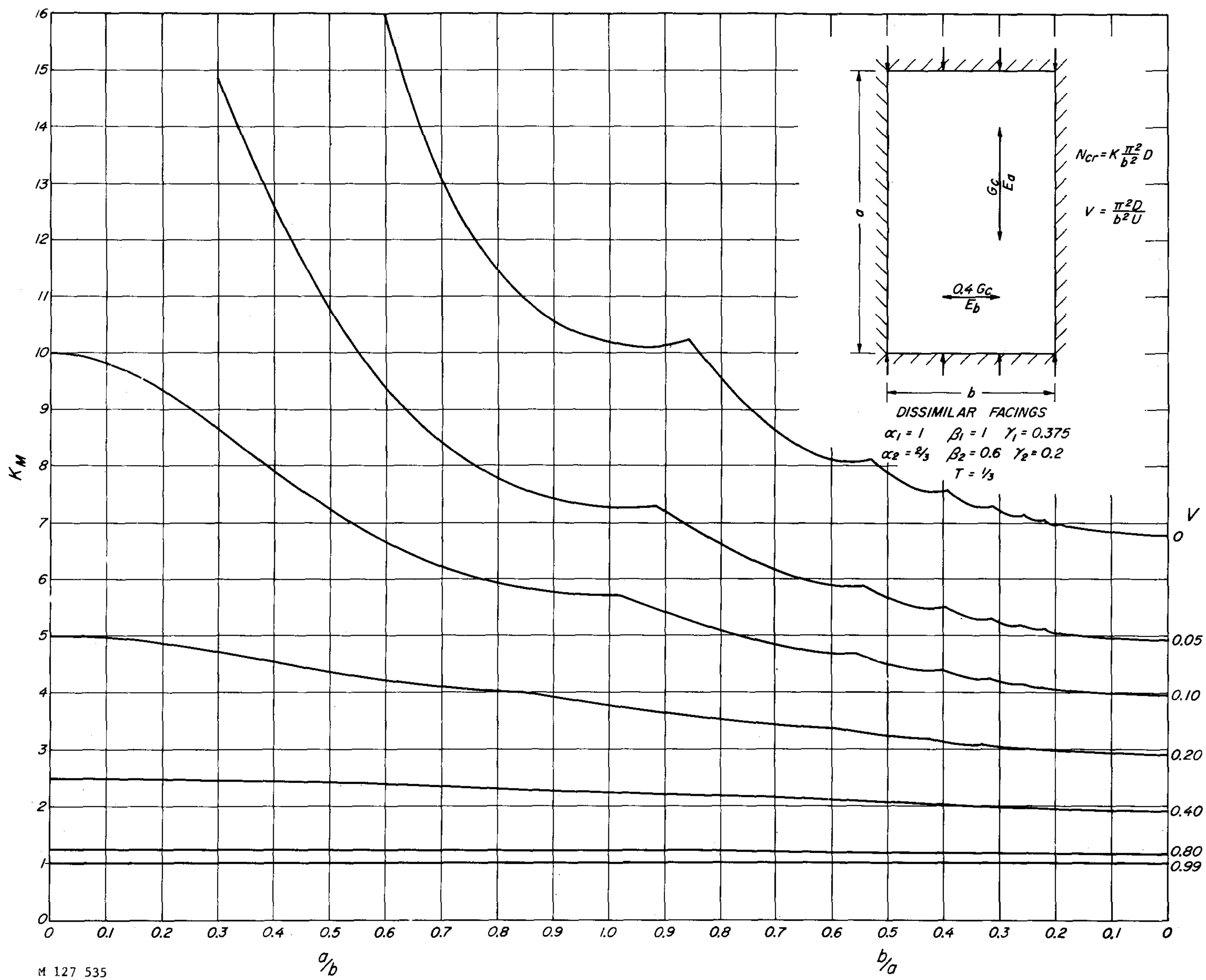
M 127 533

Figure 116.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



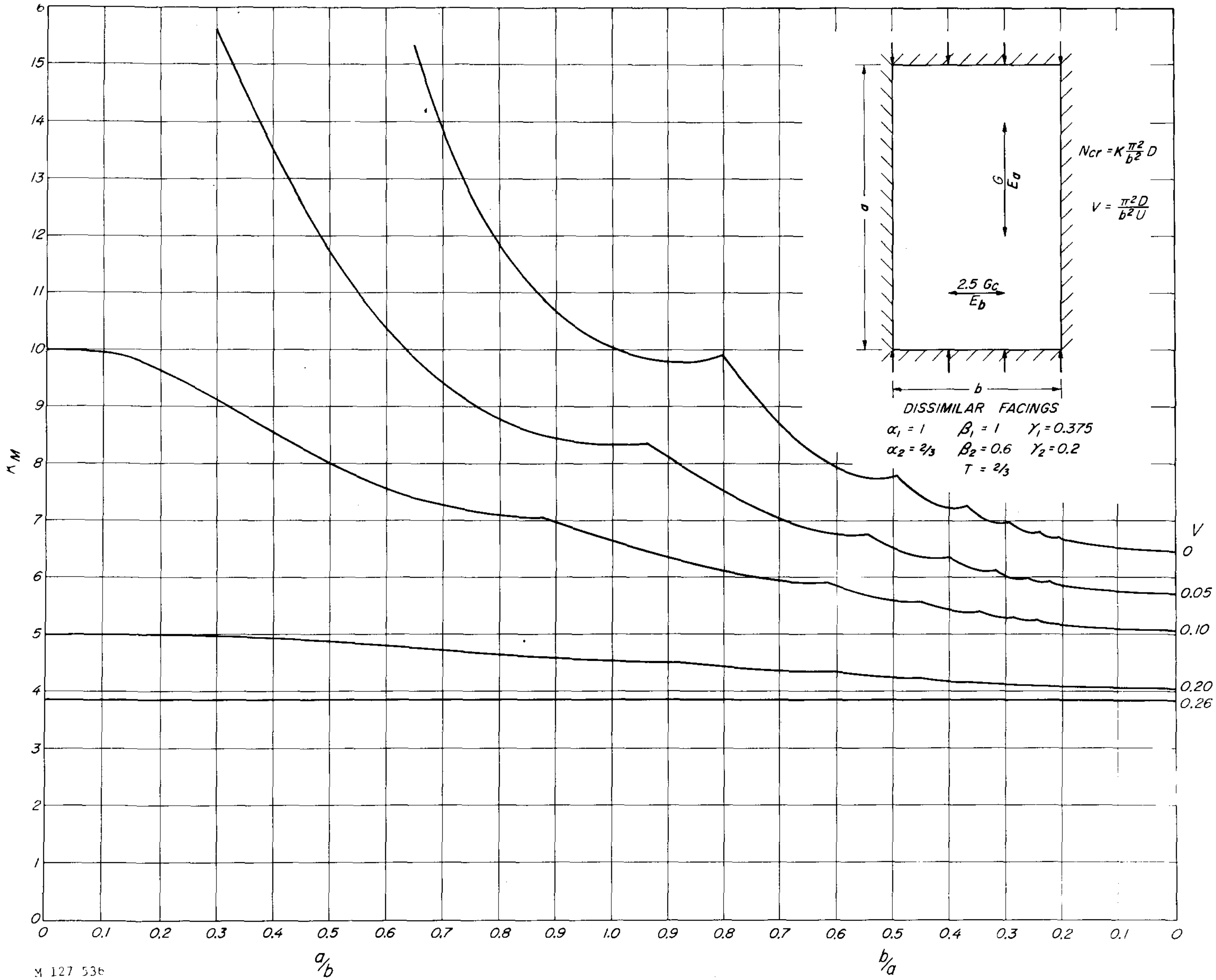
M 127 534

Figure 117.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 535

Figure 118.--Buckling coeffieints for sanwich panels in edge compression. All edges clamped.



M 127 536

Figure 119.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

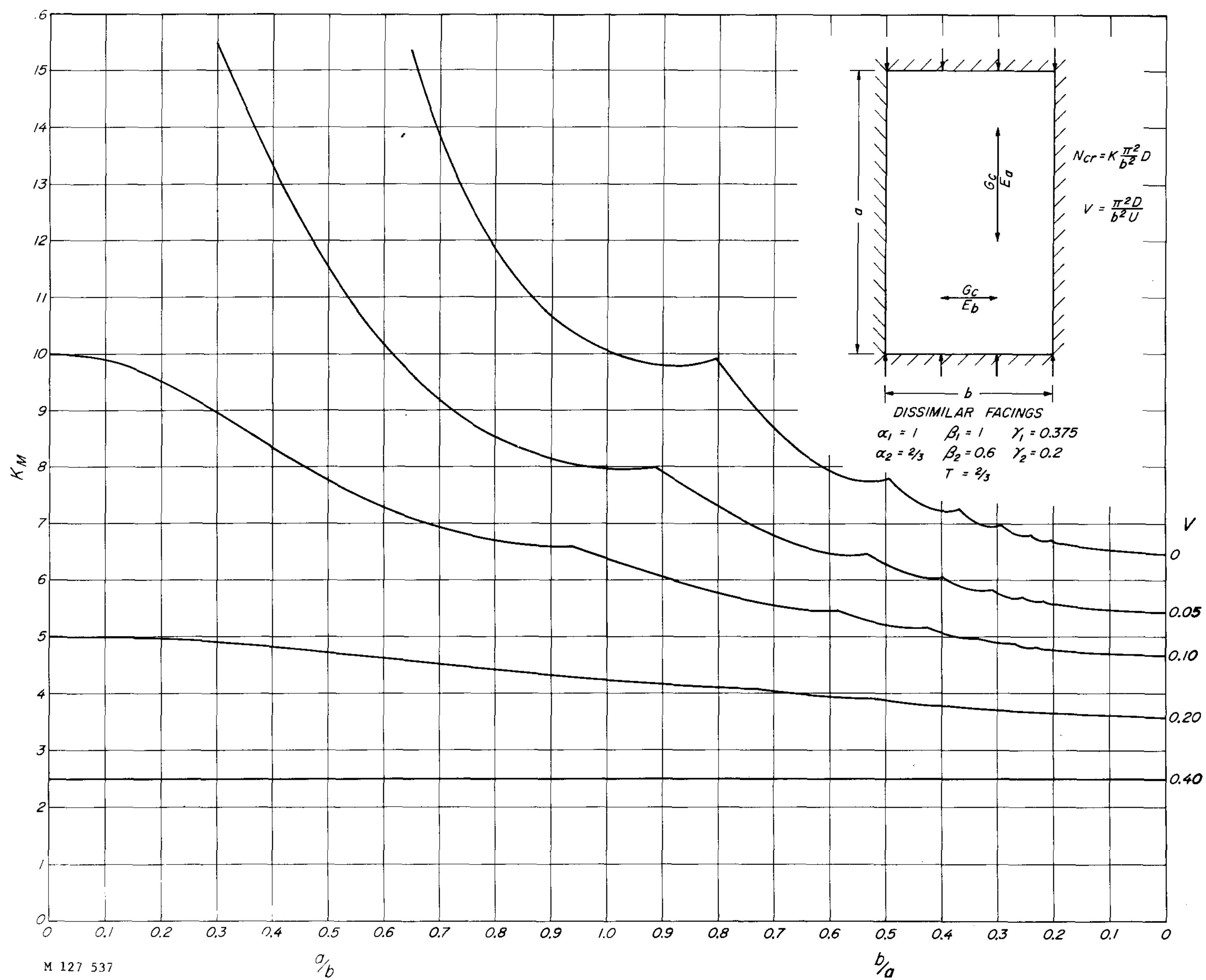
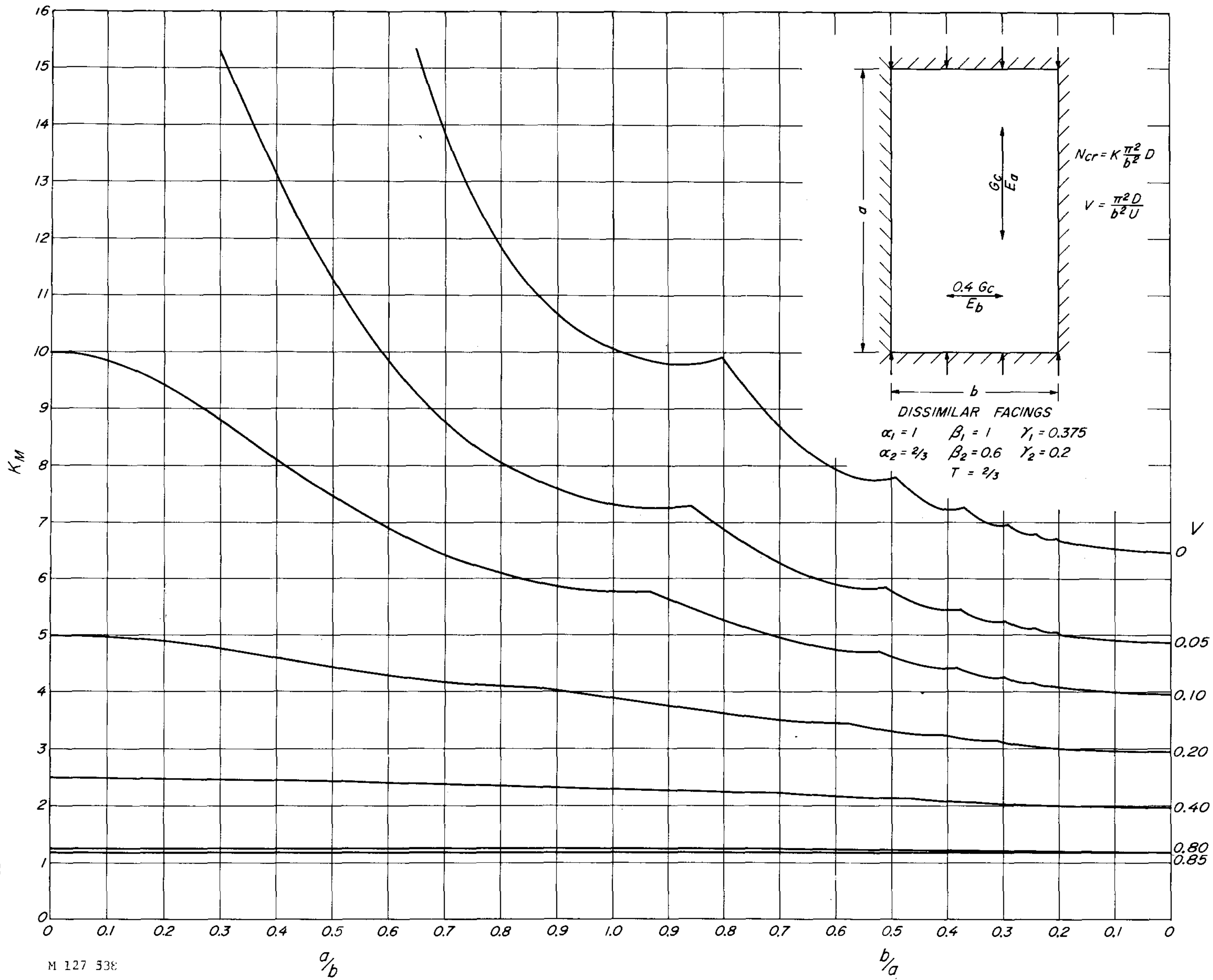


Figure 120.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.



M 127 538

Figure 12l--Buckling coefficients for sandwich panels in edge compression All edges clamped.

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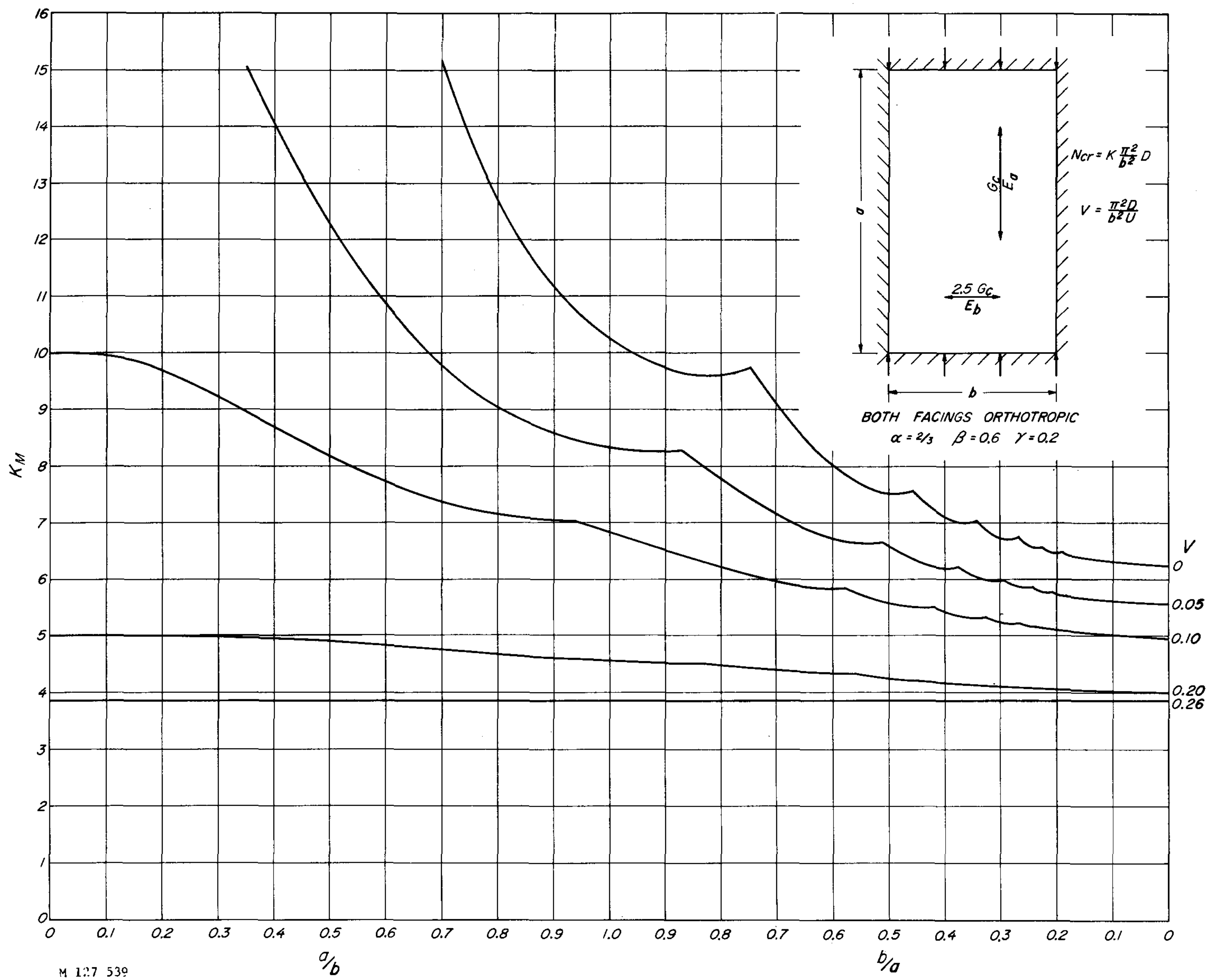


M 127 539

Figure 122.--Buckling coefficients for sandwich panels in edge compression. All edges clamped.

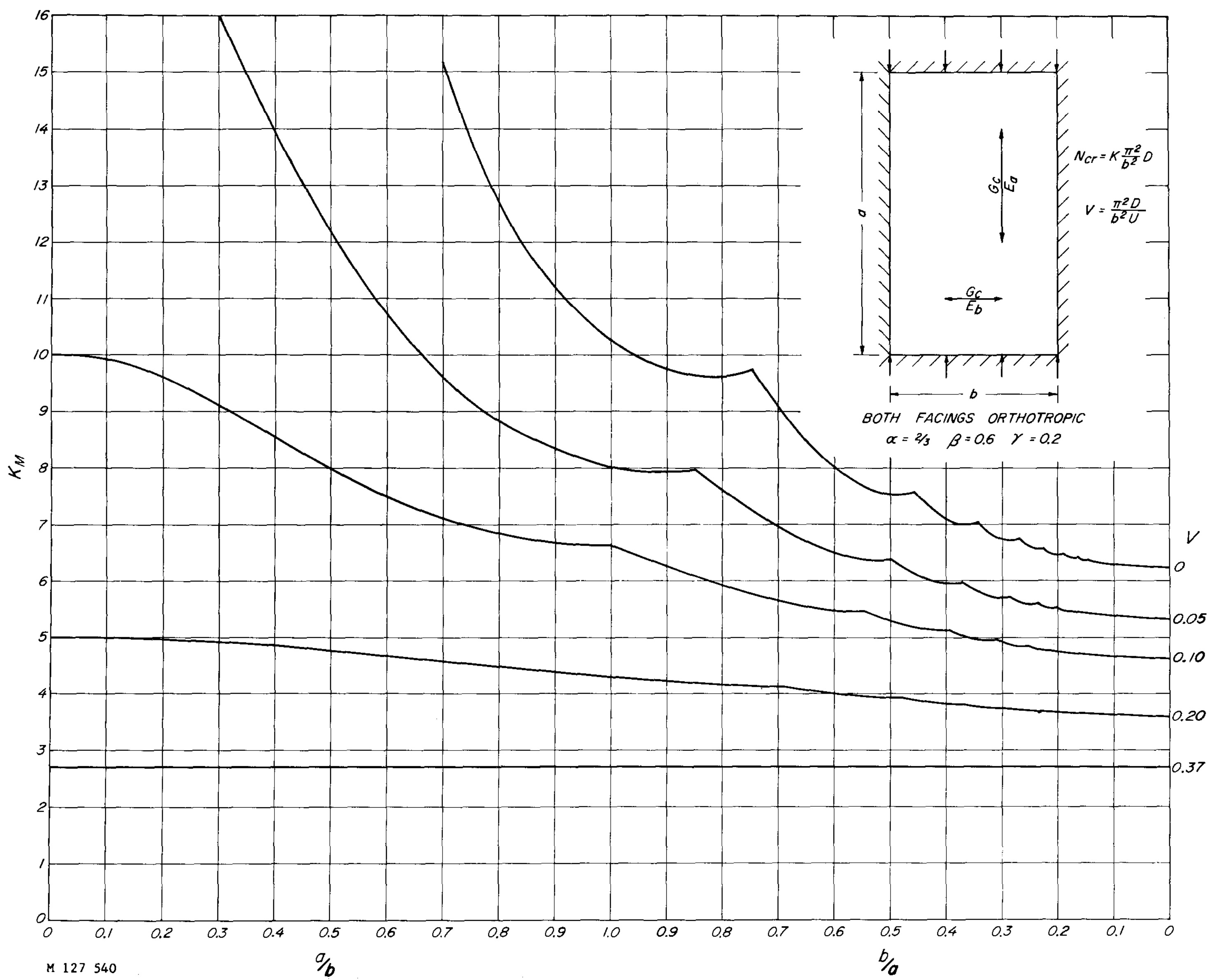


Figure 123.--Buckling coefficient for sandwich panels in edge compression. All edges clample.

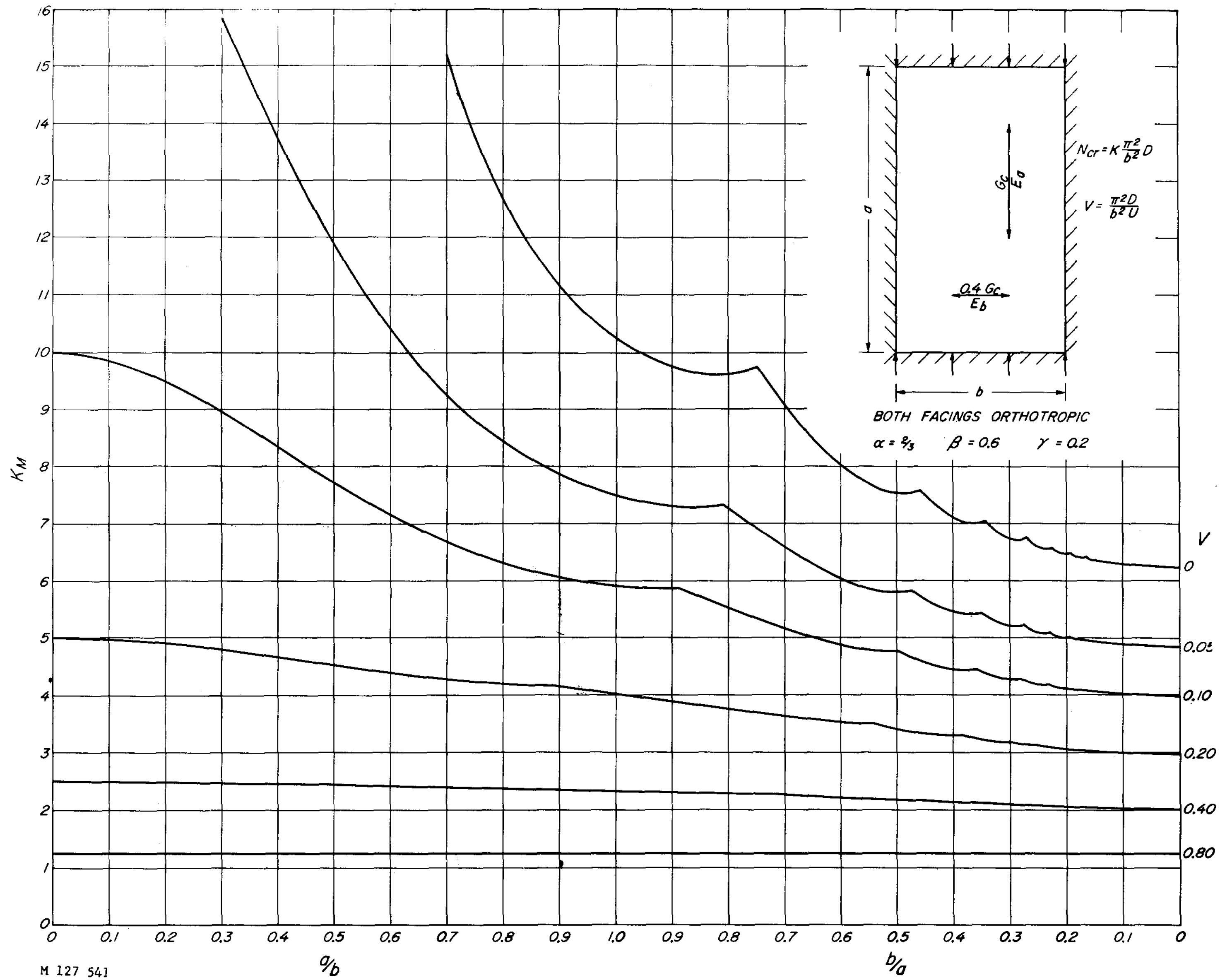
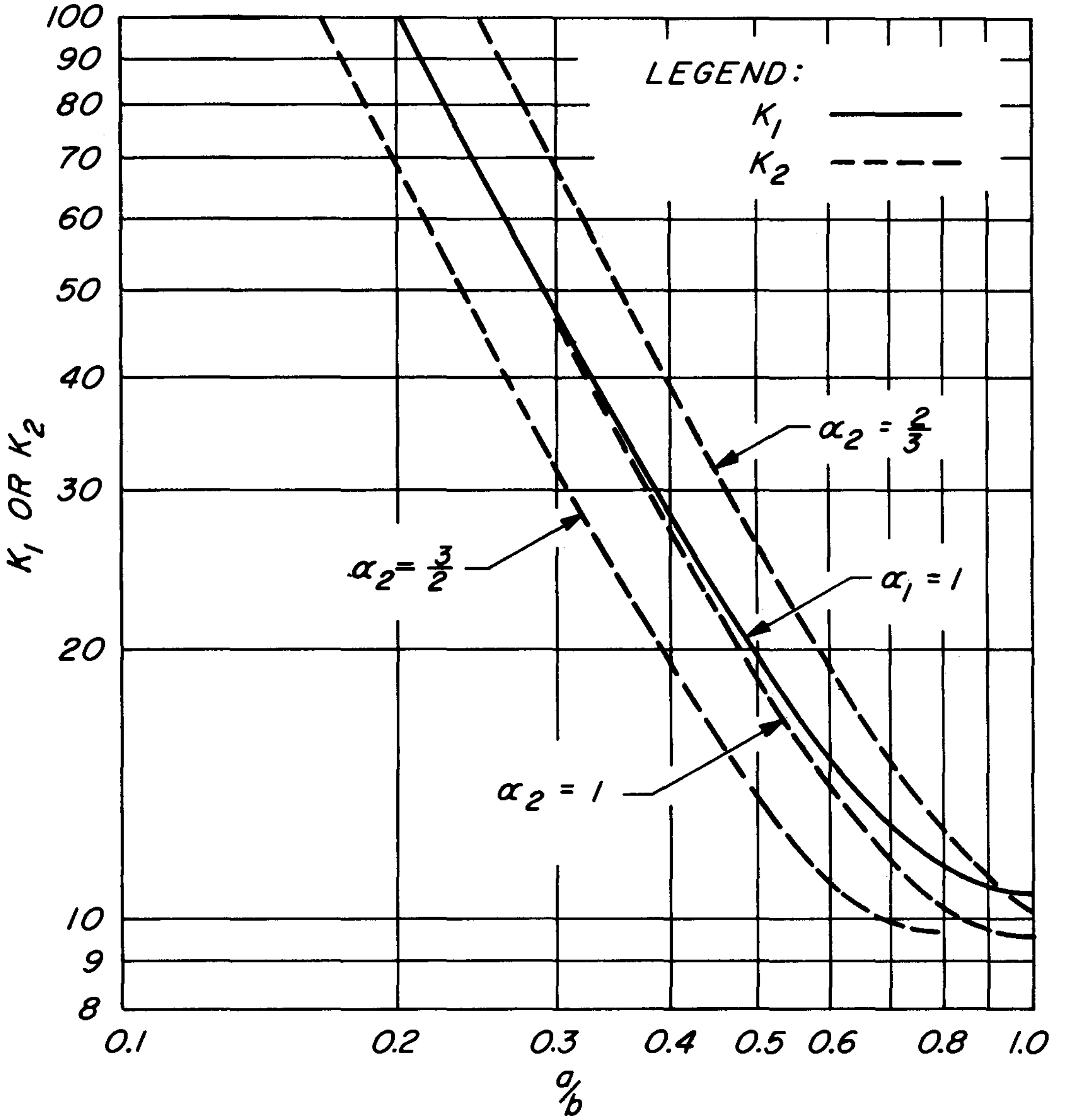


Figure 124.--Buckling coefficients for sandwich panels in edge compression All edges clamped,



M 127 841

Figure 125.--Values of $\underline{K_1}$ and $\underline{K_2}$, (n = 1), for sandwich panels with all edges clamped. $\beta_1 = 1$, $\lambda_1 = 3/8$. $\beta_2 = 0.6$, $\lambda_2 = 0.2$.

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The following lists of publications deal with investigative projects of the Forest Products Laboratory or relate to special interest groups and are available upon request:

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- Chemistry of Wood
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- Fungus and Insect Defects in Forest Products
- Glue and Plywood
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- Logging, Milling, and Utilization of Timber Products
- Mechanical Properties of Timber
- Pulp and Paper
- Structural Sandwich, Plastic Laminates, and Wood-Base Components
- Thermal Properties of Wood
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- Wood Preservation
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Note: Since Forest Products Laboratory publications are so varied in subject matter, no single catalog of titles is issued. Instead, a listing is made for each area of Laboratory research. Twice a year, December 31 and June 30, a list is compiled showing new reports for the previous 6 months. This is the only item sent regularly to the Laboratory's mailing roster, and it serves to keep current the various subject matter listings. Names may be added to the mailing roster upon request.