

Staircases shall, generally, be designed to support the design uniformly distributed load according to the load combinations specified in Chapter 2, loads. For common free standing stairs, it generally sufficient to design for gravity loading only, using the relevant load combinations.

M.1.3 Design

M.1.3.1 Empirical expressions for forces and moments (Fig.6.M.1) at critical locations of stair in terms of stair geometric and material parameters under service load are given in Table 6.M.1.

Table 6.M.1: Expressions for Free Standing Stair Forces and Moments under Service Load

Sl.	Description	Expression	Unit
1.	Deflection at landing corner, δ	$0.002 \times [1 + 3.6(A - 0.125)^{0.94}] \times [1 + 2.275(B - 0.915)^{1.1}] \times [1 + 1.017(C - 0.914)^{0.93}] \times [1 - 7.87 \times 10^{-3}(L - 2.03)] \times [1 - 0.2(H - 2.44)] \times [1 - 1.617(T - 0.1)^{0.334}] \times [1 - 1.074 \times 10^{-6}(f'_c - 14)^{0.93}]$	m
2.	Support moment, M_S	$4.712 \times [1.555 + 0.787(A - 0.05)] \times [1.06 - 0.22(B - 0.86)] \times [1.2 + 2.76(C - 0.864)] \times [1 + 0.748(L - 2.03)] \times [1 + 5.9 \times 10^{-3}(H - 2.44)] \times [0.39 + 1.73(T - 0.09)]$	kN-m
3.	Flight mid-span moment, M_F	$1.526 \times [1.1 - 1.143(A - 0.15)^{1.52}] \times [1 - 0.872(B - 0.915)^{1.365}] \times [1 + 12.22(L - 2.03)^{2.66}] \times [1 + 0.184(H - 2.44)^{2.77}] \times [1 - 5.34(T - 0.1)^{1.17}]$	kN-m
4.	Moment at flight-landing junction, M_K	$3.447 \times [1.23 + 0.512(A - 0.125)] \times [1.01 + 3.23(B - 0.915)] \times [0.85 + 0.709(C - 0.915)] \times [0.95 + 5.5(T - 0.1)^{1.03}]$	kN-m
5.	Moment at mid-landing section, M_o	$6.14 \times [1 + 0.303(A - 0.15)] \times [1 + 1.18(B - 0.915)] \times [1 + 1.06(C - 0.915)] \times [1 + 0.409(L - 2.03)] \times [1 + 0.02637(H - 2.04)] \times [1 + 1.85(T - 0.1)]$	kN-m
6.	Axial force in flights, A_F	$34.69 \times [1 + 0.236(A - 0.125)] \times [1 + 0.787(B - 0.915)] \times [1 + 0.827(C - 0.915)] \times [1 + 0.354(L - 2.03)] \times [1 - 0.157(H - 2.44)] \times [1 + 2.76(T - 0.1)]$	kN
7.	Torsion in flights, T_F	$2.312 \times [1 + 1.77(A - 0.125)] \times [1 + 0.63(B - 0.915)] \times [1 + 2.68(C - 0.915)] \times [1 - 1.423 \times 10^{-3}(L - 2.03)^{0.75}] \times [1 + 3.58(T - 0.1)]$	kN-m
8.	In-plane moment in flights, M_I	$14.35 \times [1.1 + 0.866(A - 0.15)] \times [1 + 0.984(B - 0.915)] \times [1 + 1.57(C - 0.915)] \times [1 + 0.59(L - 2.03)] \times [1 - 0.197(H - 2.44)] \times [1 + 2.6(T - 0.1)]$	kN-m
9.	Lateral shear at mid-landing section, V_o	$30.17 \times [1 - 0.276(A - 0.15)] \times [1 + 1.38(B - 0.915)] \times [1 + 0.709(C - 0.915)] \times [1 + 0.669(L - 2.03)] \times [1 - 0.24(H - 2.44)] \times [1 + 6.092(T - 0.1)^{1.3}]$	kN
In the above expressions, the unit of length is meter and the unit of force is kilo-Newton. The unit for f'_c is in MPa. The ranges of parameters for which the above expressions are applicable are as follows: $0.15 \leq A \leq 1.0$, $0.92 \leq B \leq 1.9$, $0.92 \leq C \leq 1.9$, $2.0 \leq L \leq 3.6$, $2.44 \leq H \leq 4.32$, $0.1 \leq T \leq 0.28$, $14 \leq f'_c \leq 40$.			

M.1.3.2 The empirical expressions of forces and moments given above provide working/service values corresponding to 5.0 kN/m^2 service live load and appropriate service dead load of slab and steps based on unit weight of 23.56 kN/m^3 . Forces and moments for other values of live load, L_L , may be calculated by simple proportioning. This can be reasonably done by multiplying the quantities of Table 6.M.1 by a factor $(23.56 T + L_L + 2.36)/(23.56 T + 7.36)$ where L_L is in kN/m^2 and T is in meter. Once the working/service values are obtained for desired load as described, the ultimate design values (factored) for USD method of reinforcement design may be obtained by multiplying the working values by a conversion factor equal to $(1.2D_L + 1.6L_L)/(D_L + L_L)$ where D_L is the dead load in kN/m^2 . For 5.0 kN/m^2 live load and concrete unit weight of 23.56 kN/m^3 , this conversion factor can safely be approximated as $(42.41 T + 8.0)/(35.34 T + 5.0)$. Once the values of design moments and forces are obtained, design procedure of Chapter 6 (Part 6) may be employed for the reinforcement design of flights and landing.

M.1.3.3 Moments M_S , M_K and M_O are such that they produce tension in the top fiber requiring longitudinal slab reinforcement to be placed near the top face of slab. Moment M_F produce tension in the bottom fiber of flight slab requiring longitudinal reinforcement to be placed near the bottom face of slab. Axial force A_F produce tension in upper flight and compression in lower flight. This requires tension reinforcement to be provided only in the upper flight. In-plane moment M_I acts in such a manner that it produces tension along the inner edge of upper flight and outer edge of lower flight.

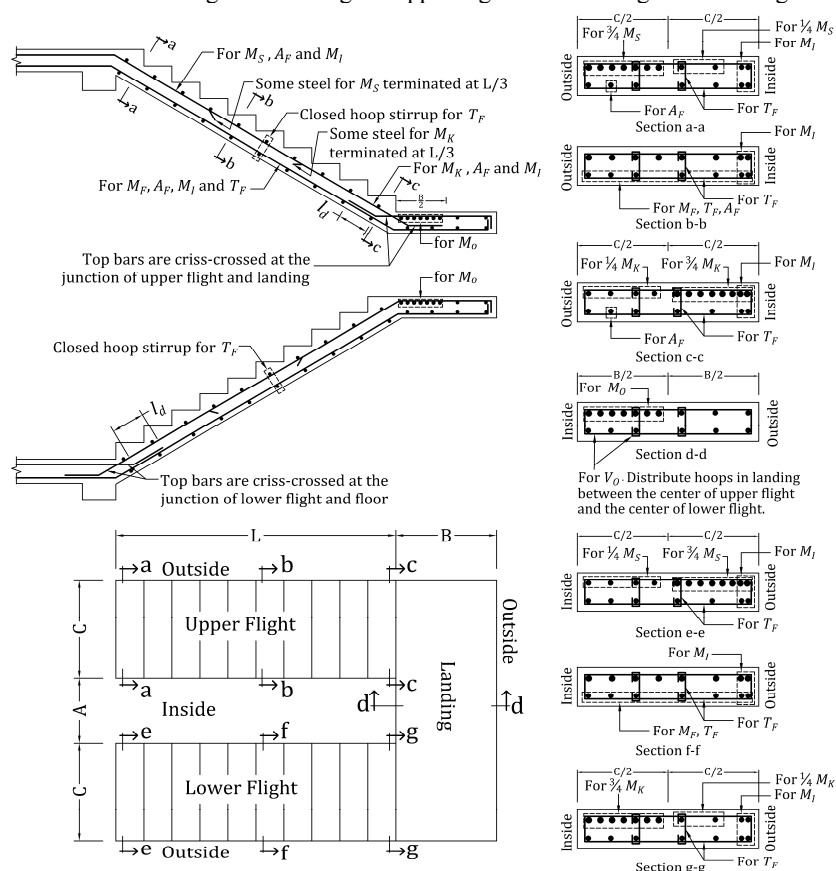


Figure 6.M.2 Recommended reinforcement layout details for free standing stair

M.1.3.4 Apart from maintaining the standard code provisions in detailing the reinforcement as stipulated elsewhere in this Code, additional detailing shall be done to take care of the features which are special to the free standing stairway. To account for the non-uniform distribution of the bending moment M_S at support across the width of the slab, 75 percent of the total negative steel shall be distributed across the outer half of the width (Zone – O in Fig. 6.M.1) of support section for both the flights and the rest of the negative steel shall be distributed within the inner half of the width of support section (Zone – I). For moment M_K , 75 percent of the total negative steel shall be distributed across the inner half of the width (Zone – I in Fig. 6.M.1) of flight-landing junction for both the flights and the rest of the negative steel shall be distributed within the outer half of the width of section (Zone – O at flight-landing junction). For moment M_o , the total negative steel shall be distributed across the inner half of the width (Landing Zone – I in Fig. 6.M.1) and the rest of the section shall be provided with nominal reinforcement as per provisions of Chapter 6. At mid-span of flights, the positive steel required for M_F shall be distributed uniformly across the section. Longitudinal steel required to resist flight in-plane moment M_l shall be placed near the inner edge in Zone-I of upper flight and near the outer edge in Zone-O of lower flight. Longitudinal steel required to resist tensile axial force A_F in upper flight may be distributed across the section of upper flight. Closed rectangular hoop reinforcements accompanied by cross ties shall be designed to resist the action of torsion in flights and lateral shear at mid-landing section. The suggested bar detailing for the free standing stairway is shown in Figure 6.M.2.

M.2 Sawtooth Stair

M.2.1 Loading

Sawtooth (slab less) stair shall be designed to support the design ultimate load according to the load combinations specified in Chapter 2, Loads.

M.2.2 Distribution of Load

Where flights or landing are embedded at least 110 mm into the walls and are designed to span in the direction of the flight, a 150 mm strip may be deducted from the loaded area and the effective breadth of the section may be increased by 75 mm for the purpose of design (Figure 6.M.3).

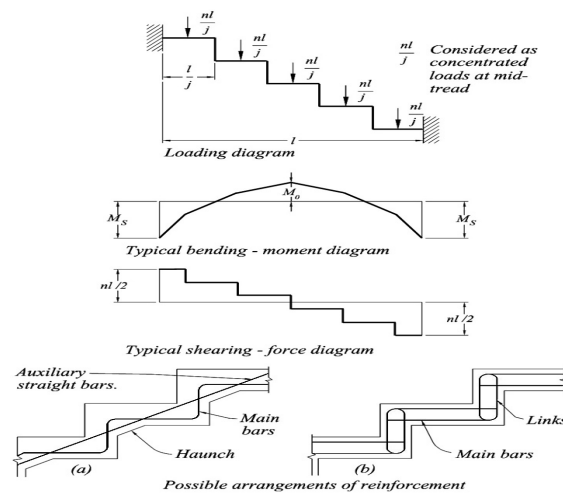


Figure 6.M.3 Elements of saw-tooth stair and typical reinforcement arrangements

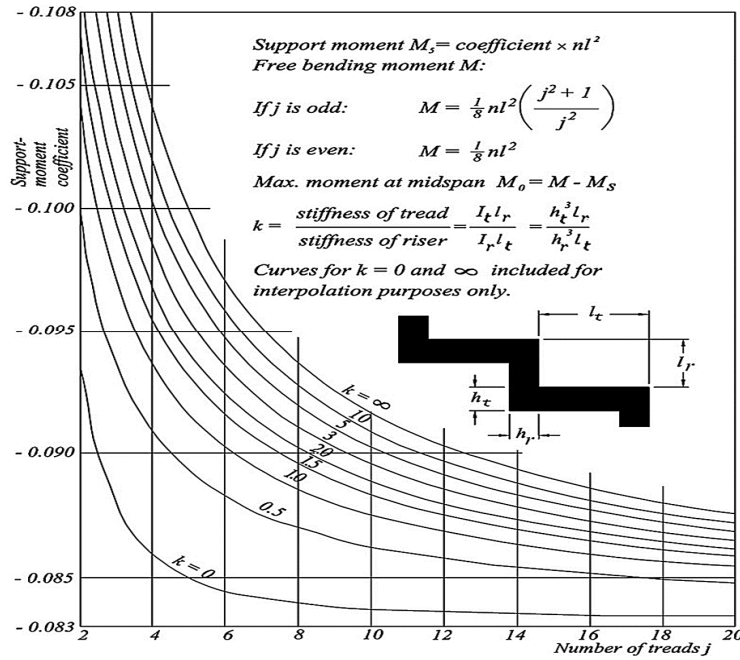


Figure 6.M.4 Support moment coefficients for saw-tooth stair

M.2.3 Effective Span

Sawtooth stairs shall be supported with stringer beams or walls at landing levels (Figure 6.M.3). The effective span for the stair shall be the going of the stair measured horizontally (Figure 6.M.3) from the face of the stringer beam or wall.

M.2.3.1 Design

The support moments for sawtooth stairs are given by:

$$M_s = \frac{nl^3 (k_{11} + k_0 k_{13})}{j^3 (k_{13} + k_0 k_{14})} \quad (6.M.1)$$

Where, k_o = stiffness of tread/stiffness of riser and j is the number of treads and n is the width of flight (Figure 6.M.3).

If j is odd: $k_{11} = \frac{1}{16} j^2 + \frac{1}{48} j(j-1)(j-2),$

$$k_{12} = \frac{1}{16} (j-1)^2 + \frac{1}{48} j(j-1)(j-2)(j-3),$$

$$k_{13} = \frac{1}{2} j, \quad k_{14} = \frac{1}{2} (j-1).$$

If j is even: $k_{11} = \frac{1}{48} j(j-1)(j-2),$ $k_{12} = \frac{1}{48} (j-1)(j-2)(j-3),$

$$k_{13} = \frac{1}{2} (j-1),$$

$$k_{14} = \frac{1}{2} (j-2)$$

The chart on Figure 6.M.4 gives the support-moment coefficients for various ratios of stiffness of tread/stiffness of riser and numbers of treads. Having found the support moment, the maximum mid-span bending moment can be alternatively determined by using the appropriate expression on the Figure 6.M.4 and subtracting the support moment.

M.2.4 Detailing

Typical bending-moment and shearing-force diagrams for a stair are shown on Figure 6.M.3 together with suggested arrangements of reinforcement. The re-entrant corners of the stair-profile shall be designed for stress concentrations. This has to be facilitated by providing twice of the reinforcements calculated from Eq. 6.M.1 and Figure 6.M.4. Fillets or haunches can also be incorporated in lieu at these junctions. The method of reinforcing the stair shown in diagram (a) of Figure 6.M.3 is very suitable but is generally only practicable if haunches are provided. Otherwise the arrangement shown in diagram (b) should be adopted.

M.3 Helicoidal Stair

M.3.1 Loading

Helicoidal stair shall be designed to support the design ultimate load according to the load combinations specified in Chapter 2, Loads.

M.3.2 Geometry

The pertinent geometry of the Helicoidal stair is given at Figure 6.M.5 where:

- b : Width of stair slab
- h : Thickness of the stair slab
- n : Total load per unit length projected along centre-line of load
- R_l : Radius of centre-line of loading = $(2/3)(R_0^3 - R_i^3)/(R_0^2 - R_i^2)$
- R_2 : Radius of centre-line of steps = $(1/2)(R_i + R_o)$, where R_i and R_o are the internal and external radii of the stair, respectively
- θ : Angle subtended in plan between point considered and midpoint of stair
- β : Total angle subtended by helix in plan
- ϕ : Slope of tangent to helix center-line measured from horizontal
- M_o : Bending moment at midpoint of stair.
- H : Lateral shear at the midpoint of stair.
- I_1, I_2 : Second moment of area of stair section about horizontal axis and axis normal to slope, respectively

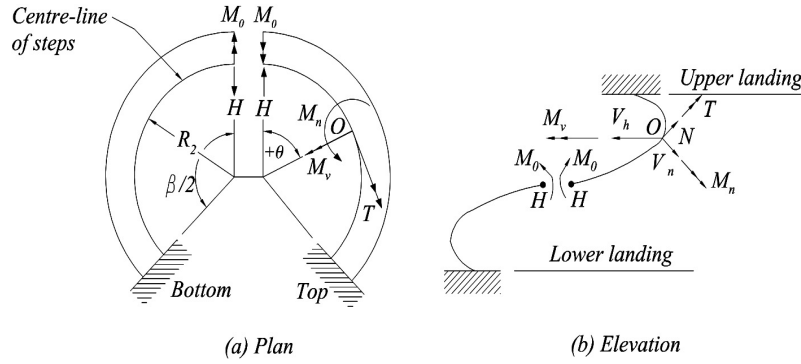


Figure 6.M.5 Elements of helicoidal stair

M.3.3 Effective Span

Helicoidal stairs shall be supported with stringer beams at landing levels (Figure 6.M.5). The effective span for the stair shall be βR , where β is the total angle subtended by helix in plan measured horizontally (Figure 6.M.5) from the face of the stringer beams.

M.3.4 Depth of Section

The depth of the section shall be taken as the minimum thickness perpendicular to the soffit of the stair unless otherwise the large geometric dimensions warrant calculating the deflections through a suitable numerical analysis.

M.3.5 Design

The moments, thrust, torsion and shear forces shall be obtained from the following equations:

Lateral moment (in-plane moment):

$$M_n = M_o \sin \theta \sin \phi - HR_2 \theta \tan \phi \cos \theta \sin \phi - HR_2 \sin \theta \cos \phi + nR_1 \sin \phi (R_1 \sin \theta - R_2 \theta) \quad (6.M.2)$$

Torsional moment:

$$T = (M_o \sin \theta - HR_2 \theta \cos \theta \tan \phi + nR_1^2 \sin \theta - nR_1 R_2 \theta) \cos \phi + HR_2 \sin \theta \sin \phi \quad (6.M.3)$$

Vertical moment (bending moment):

$$M_y = M_o \cos \theta + HR_2 \theta \tan \phi \sin \theta - nR_1^2 (1 - \cos \theta) \quad (6.M.4)$$

Thrust (axial force):

$$N = -H \sin \theta \cos \phi - nR_1 \theta \sin \phi \quad (6.M.5)$$

Lateral shearing force across stair:

$$V_n = nR_1 \theta \cos \phi - H \sin \theta \sin \phi \quad (6.M.6)$$

Radial horizontal shearing force:

$$V_h = H \cos \theta \quad (6.M.7)$$

Where,

$$M_o = \text{redundant moment acting tangentially at mid-span} = k_1 n R_2^2 \quad (6.M.8)$$

$$H = \text{horizontal redundant force at mid-span} = k_2 n R_2 \quad (6.M.9)$$

$$M_{ys} = \text{vertical moment at supports} = k_3 n R_2^2 \quad (6.M.10)$$

The values of coefficients k_1 , k_2 and k_3 can be obtained from the charts provided in Figures 6.M.6 to 6.M.9 for different combinations of R_1/R_2 and b/h ratios. To determine values of coefficients k_1 , k_2 and k_3 for other intermediate values of R_1/R_2 and b/h ratios, interpolations may be performed.

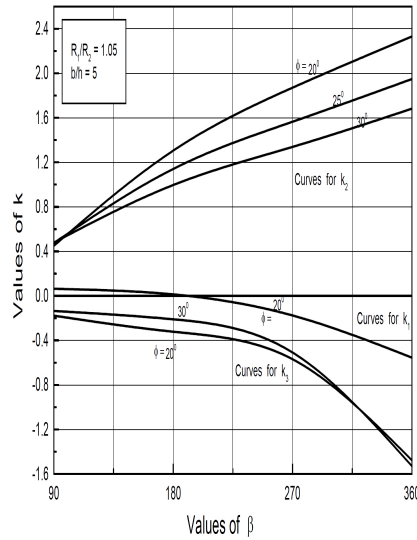


Figure 6.M.6 Design charts for helicoidal stair slabs for $R_1/R_2 = 1.05$ and $b/h = 5$.

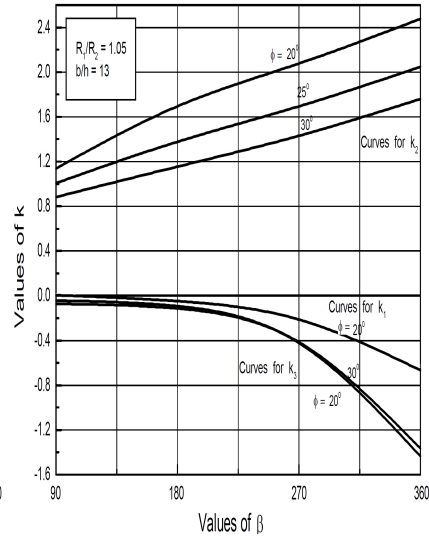


Figure 6.M.7 Design charts for helicoidal stair slabs for $R_1/R_2 = 1.05$ and $b/h = 13$.

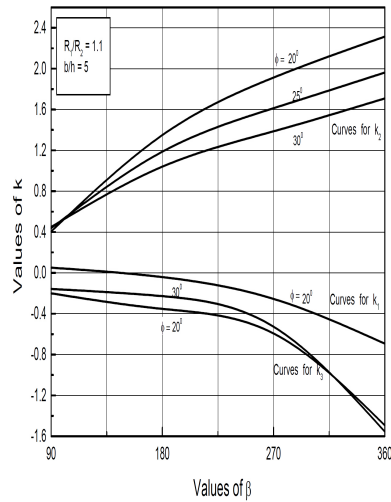


Figure 6.M.8 Design charts for helicoidal stair slabs for $R_1/R_2 = 1.1$; $b/h = 5$.

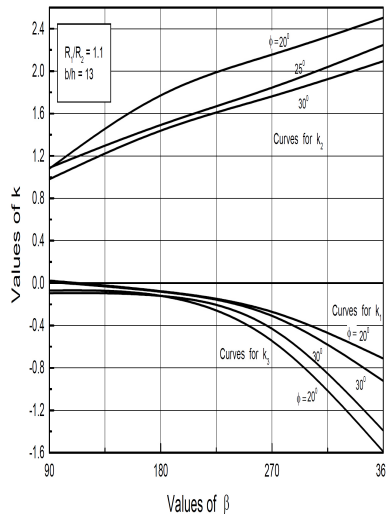


Figure 6.M.9 Design charts for helicoidal stair slabs for $R_1/R_2 = 1.1$; $b/h = 13$.

PART VI
Appendix N
Prequalification of Beam-Column and
Link-to-Column Connections

N.1 Scope

This Appendix contains minimum requirements for prequalification of beam-to-column moment connections in special moment frames (SMF), intermediate moment frames (IMF), and link-to-column connections in eccentrically braced frames (EBF). Prequalified connections are permitted to be used, within the applicable limits of prequalification, without the need for further qualifying cyclic tests. When the limits of prequalification or design requirements for prequalified connections conflict with the requirements of these Provisions, the limits of prequalification and design requirements for prequalified connections shall govern.

N.2 General Requirements

N.2.1 Basis for Prequalification

Connections shall be prequalified based on test data satisfying Section N.3, supported by analytical studies and design models. The combined body of evidence for prequalification must be sufficient to assure that the connection can supply the required interstory drift angle for SMF and IMF systems, or the required link rotation angle for EBF, on a consistent and reliable basis within the specified limits of prequalification. All applicable limit states for the connection that affect the stiffness, strength and deformation capacity of the connection and the seismic load resisting system (SLRS) must be identified. These include fracture related limit states, stability related limit states, and all other limit states pertinent for the connection under consideration. The effect of design variables listed in Section N.4 shall be addressed for connection prequalification.

N.2.2 Authority for Prequalification

Prequalification of a connection and the associated limits of prequalification shall be established by a connection prequalification review panel (CPRP) approved by the authority having jurisdiction.

N.3 Testing Requirements

Data used to support connection prequalification shall be based on tests conducted in accordance with Appendix Q. The CPRP shall determine the number of tests and the variables considered by the tests for connection prequalification. The CPRP shall also provide the same information when limits are to be changed for a previously prequalified connection. A sufficient number of tests shall be performed on a sufficient number of nonidentical specimens to demonstrate that the connection has the ability and reliability to undergo the required interstory drift angle for SMF and IMF and the required link rotation angle for EBF, where the link is adjacent to columns. The limits on member sizes for prequalification shall not exceed the limits specified in Appendix Q, Section Q.5.2.