

CIVL471 DESIGN OF RC STRUCTURES

LECTURE NOTE #7

EXTERNAL DISTURBANCES

Buildings and Design Code

A code is a set of technical specifications and standards that control major details of analysis, design, and construction of buildings, equipment, and bridges.

The aim of codes is to produce safe, economical structures to protect public from poor and inadequate design and construction.

- Structural Codes and Building Codes

- These codes are for the design of particular structures (e.g. buildings, highway bridges or nuclear power plants) and proper use of a specific material (e.g. steel, reinforced concrete, aluminum, or wood). Some codes are established to cover construction in a given region and provide provisions of particular interest such as soil conditions, wind loads, earthquake loads etc. Examples of codes are:

- Building Code Requirements for Reinforced Concrete (ACI 318)
- Standard Specifications for Highway Bridges
- Building Code Requirements for Reinforced Concrete (TS 500)
- Design Loads for Buildings (TS 498)
- Specifications for Structures to be Built in Disaster Areas (Turkish Earthquake Code)

Loads

Structures must be designed so that they will not fail or deform excessively under load. Engineers must anticipate probable loads a structure must carry. Structures be able to carry all the loads that may act on throughout its economical life. The design loads specified by the codes are satisfactory in general. However, depending on the nature of the structure, an engineer may refer to experiments etc. and increase the minimum loads specified by the code.

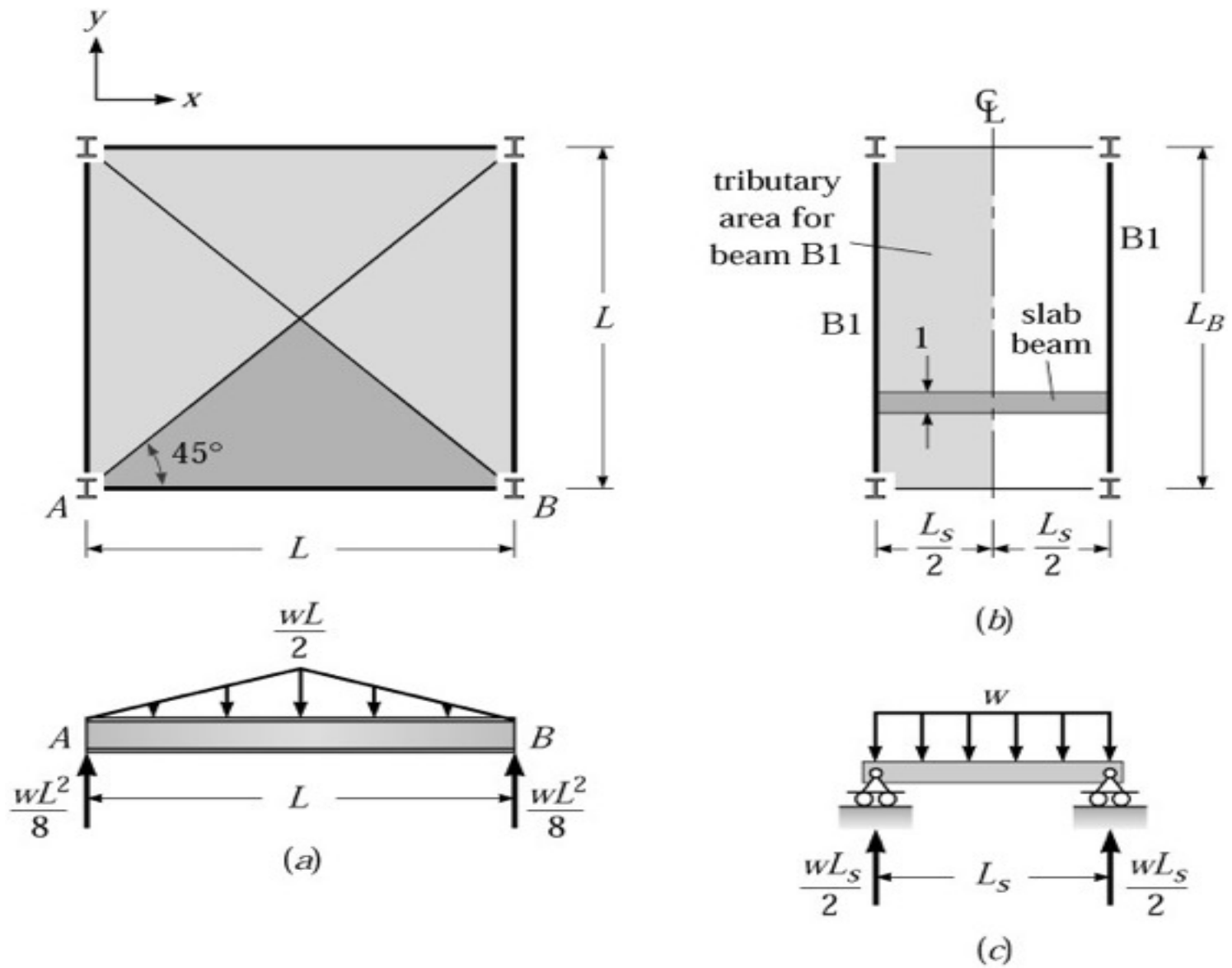
- Typical loads acting on structures are:
 - Dead Loads
 - Live Loads
 - Construction Loads (settlement in supports, lack of it of element temperature changes etc).
 - Wind Loads
 - Earthquake Loads
 - etc.

- Dead Loads

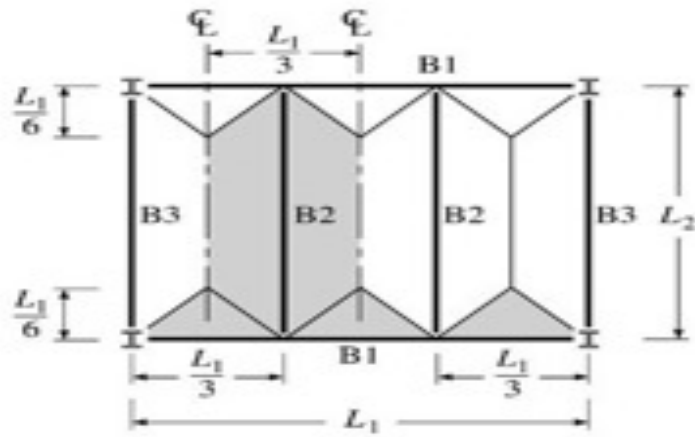
The load associated with the weight of the structure and its permanent components (floors, ceiling, ducts etc.) is called the *dead load*. Dead loads can not be calculated exactly before the design since the dimensions of the members are not known at the beginning. Therefore, initially magnitude of the dead load is estimated for preliminary design and after sizing of the members it is calculated more accurately.

- Distribution of Dead Load to Framed Floor Systems

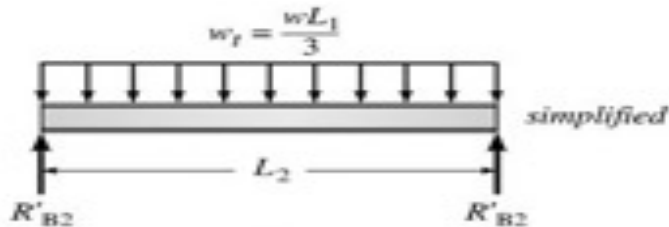
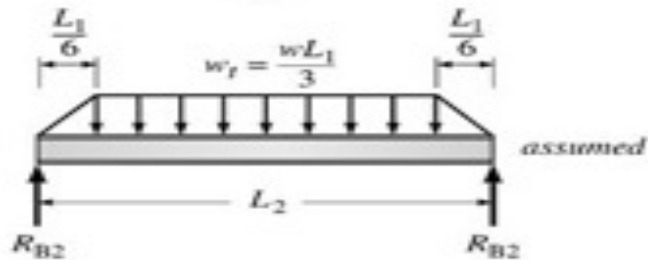
Floor systems consist of a reinforced concrete slab supported on a rectangular grid of beams and load of the slab is carried by these beams. The distribution of load to a floor beam depends on the geometric configuration of the beams forming the grid. The area of slab that is supported by a particular beam is termed the beam's tributary area (see figure)



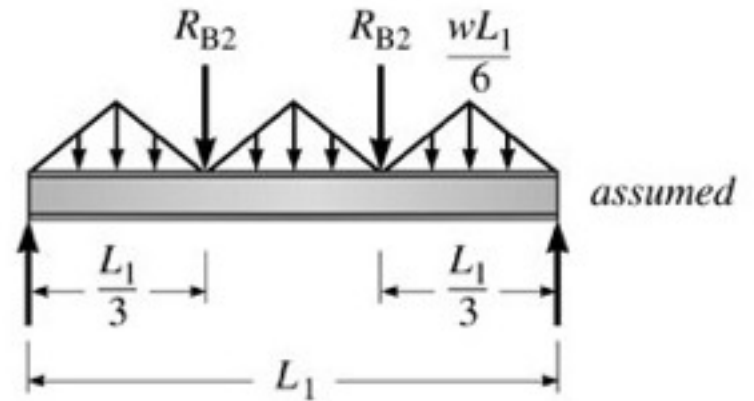
Concept of tributary area; a) square slab, all edge beams support a triangular area; (b) two edge beam divide load equally; (c) load on a 1 ft of slab in (b).



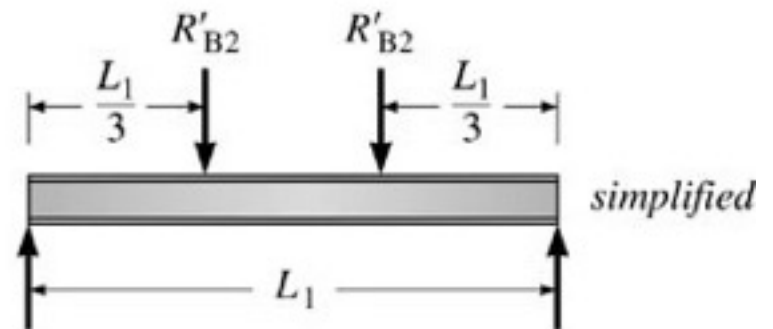
(d)



(e)



(f)



(g)

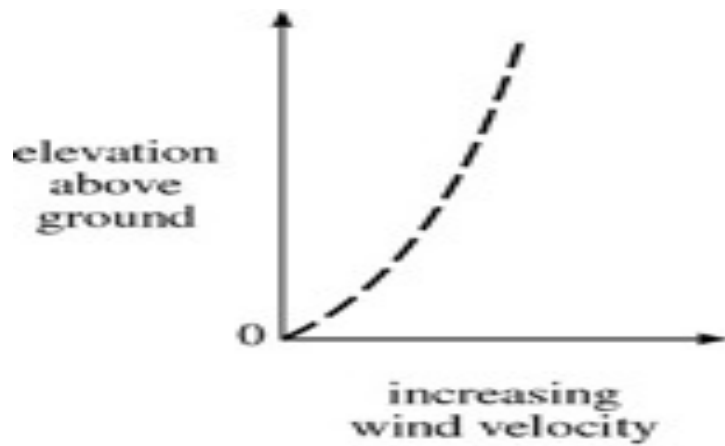
(d) tributary areas for beams B1 and B2 shown shaded, all diagonal lines slope at 45°; (e) top figure shows most likely load on beam B2 in figure (d); bottom figure shows simplified load distribution on beam B2; (f) most likely load on beam B1; (g) simplified load distribution to beam B1.

- Live Loads

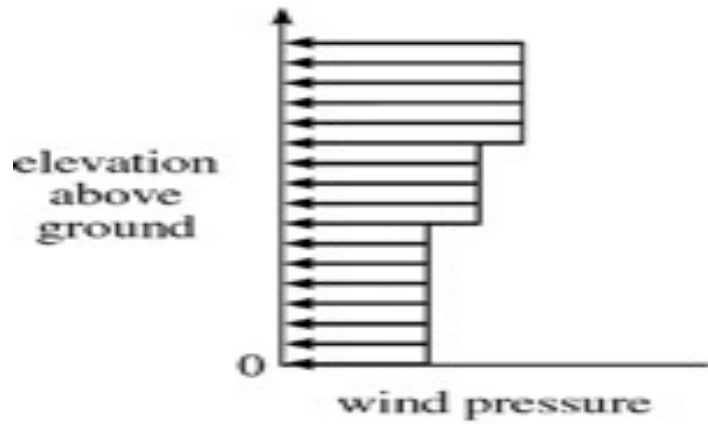
Loads that can be moved on or off a structure are classified as *live loads*. Live loads include the weight of people, furniture, machinery, and other equipment. Live loads specified by codes for various types of buildings represent a conservative estimate of the maximum load likely to be produced by the intended use of the building. In addition to long term live load, when sizing members short term construction loads (if these loads are large) should be considered.

- Wind Loads

The magnitude of wind pressure on a structure depends on the wind velocity, the shape and stiffness of the structure, the roughness and profile of the surrounding ground, and influence of adjacent structures. As wind pressure may be computed from wind velocities an alternative is the equivalent horizontal wind pressure specified by codes

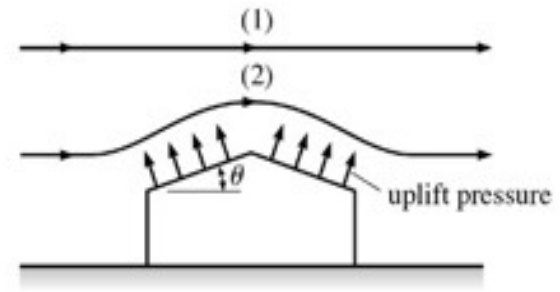


(a)

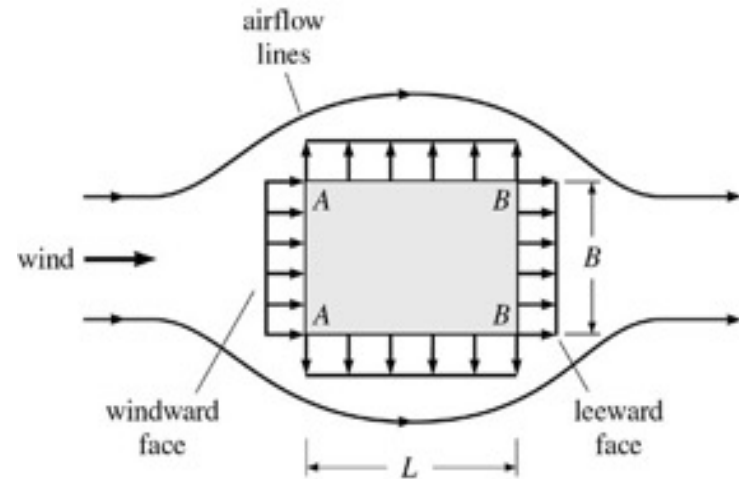


(b)

a) variation of wind velocity with distance above ground surface; (b) variation of wind pressure specified by typical building codes for windward side of building



(a)

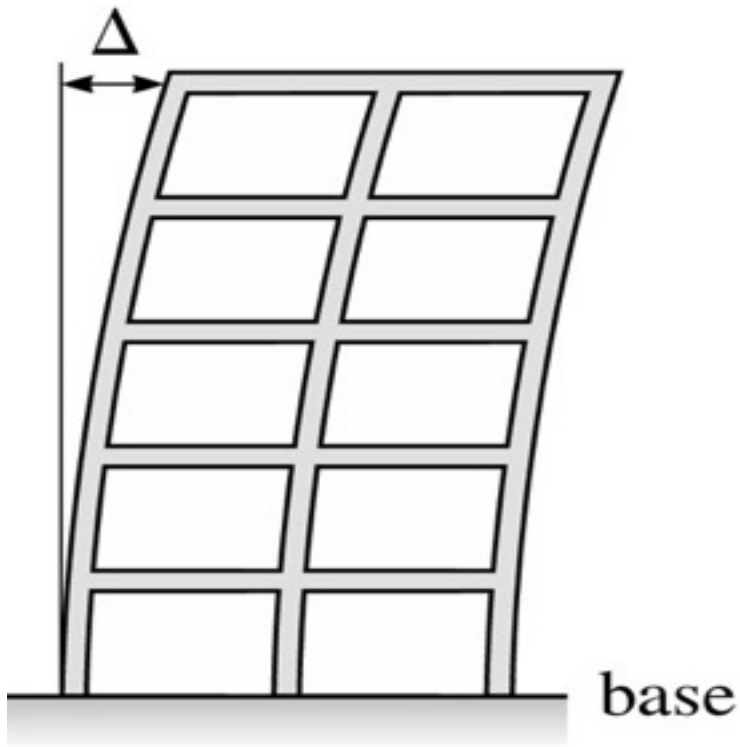


(b)

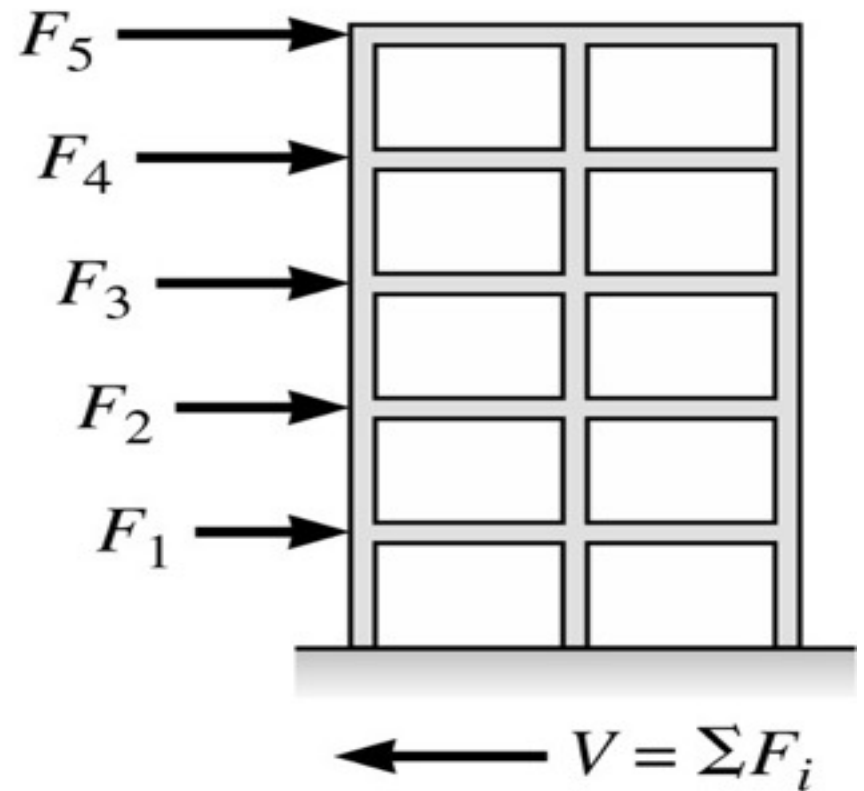
a) uplift pressure on a sloping roof; (b) Increased velocity creates negative pressure (suction) on sides and leeward face

- Earthquake Forces

The ground motions created by major earthquake forces cause buildings to sway back and forth. Assuming the building is fixed at its base, the displacement of floors will vary from zero at the base to a maximum at the roof. As the floors move laterally, the lateral bracing system is stressed as it acts to resist the lateral displacement of the floors. The forces associated are inertia forces and related with the weight and stiffness of the structure.



(a)



(b)

- (a) Displacement of floors as building sways;
- (b) inertia forces produced by motion of floors

SERVICEABILITY, STRENGTH AND SAFETY OF THE STRUCTURE

- Any structure should not fail when subjected to service loads. Service loads are the loads used in design. They should also be reasonably safe. Excessive deformations of structural members, even if they are strong enough may create problems under the service conditions. Besides, cracks that form in the concrete should be invisible, in some structures concrete should not crack at all. For example, cracks are not desirable in water tanks, reactor buildings etc. All these requirements are known as the serviceability of the structure.

There are a number of uncertainties in the analysis, design and construction processes. For this reason neither strength nor serviceability of a structure can be defined precisely. However as it will be explained later, a margin of safety may be provided for both strength and serviceability.

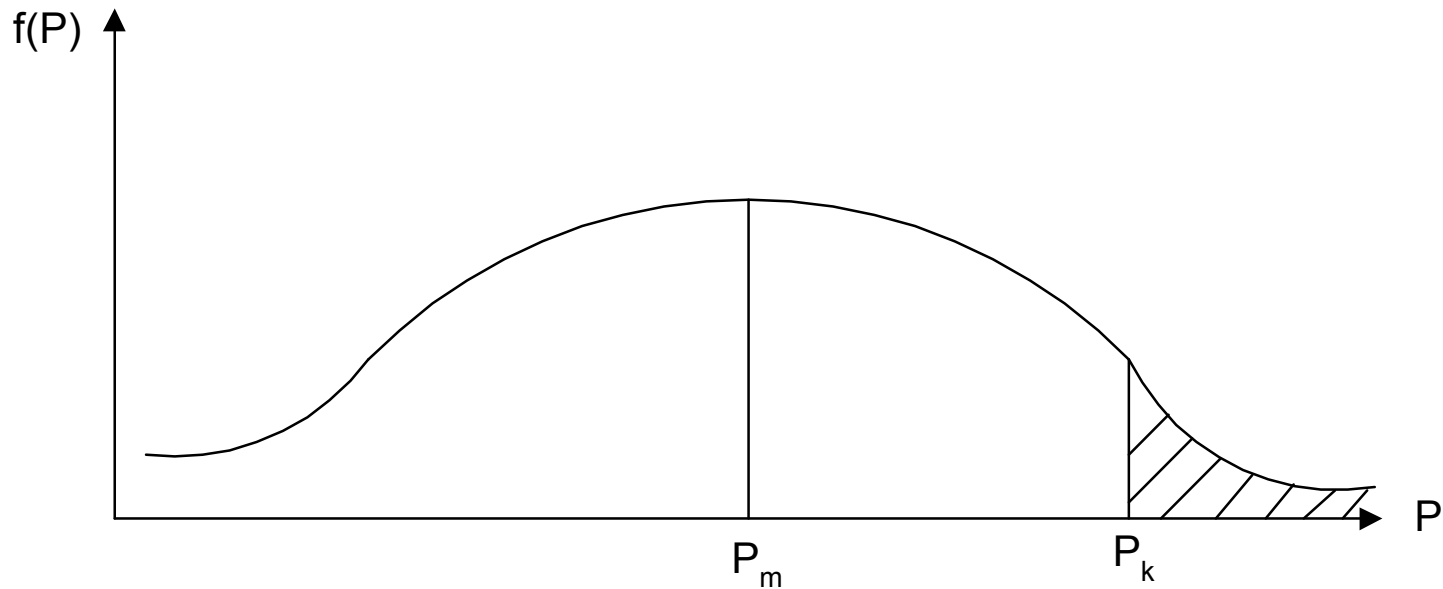
The main reasons of uncertainties are listed below:

- Actual loads may be different than the assumed ones.
- Distribution of loads may be different than that assumed.
- Calculated load effects (stresses etc.) may be different than the actual effects because of the assumptions and simplifications made in analysis.
- Actual behavior of the structure may not be as assumed.
- Errors may be made in the dimensions of the members during the construction.
- Errors may be made during the placing of reinforcement.
- Actual material strength may be different than the specified strength.

Margin of safety of a structure should be related to the probable results of a failure.

1.5. STATISTICAL APPROACH FOR SAFETY MARGIN

- Maximum load of a structural element during the lifetime of a structure is not certain. Variation of the load may be considered random and may be approximated in the form of a frequency curve, as shown below

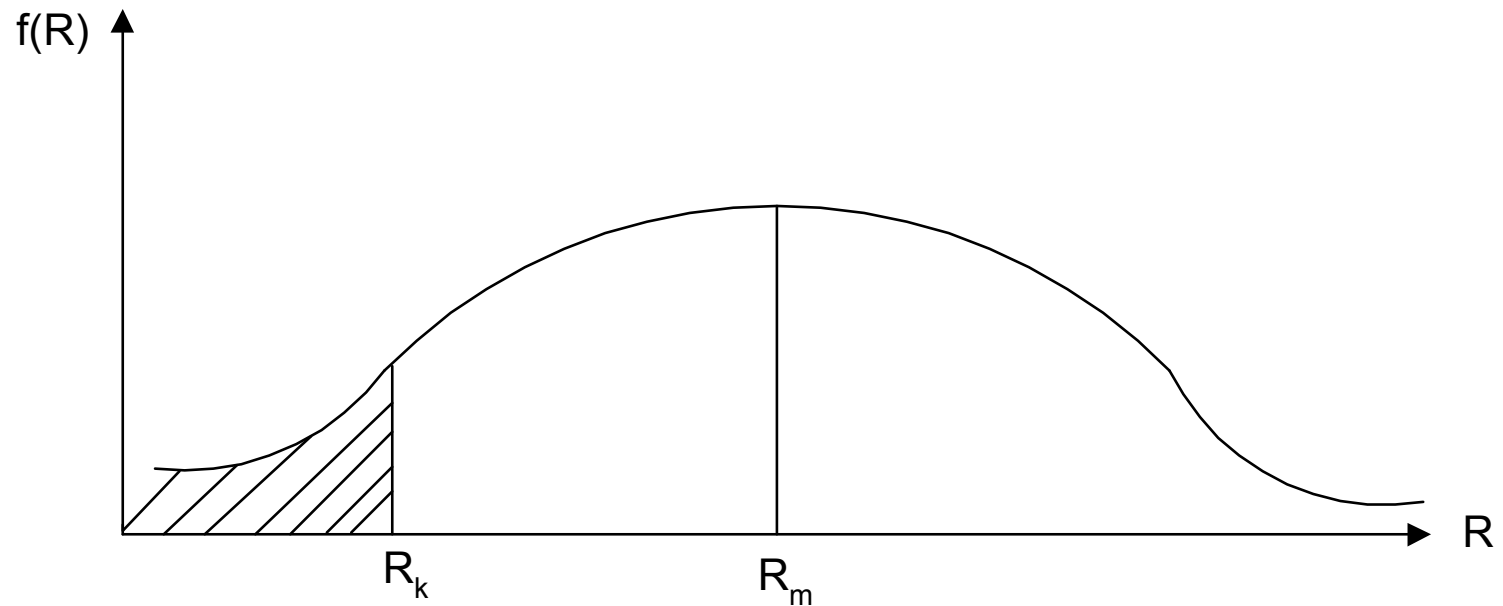


Shaded area represents the probability of occurrence of loads larger than P_k . P_m is mean value of loads. It is a common practice to use a conservative value greater than P_m in design. For example a characteristic value P_k can be considered for this purpose. If standard deviation σ_p is the following equation can be written as

$$P_k = P_m + u \cdot \sigma_p \quad (0.1)$$

u is a factor depending on the shaded area shown.

- TS 500, which is code of practice for the design of reinforced concrete members, specifies the characteristic load P_k as the load given by TS 498. Therefore, the designer has not to use equation 0.1.
- Actual strength of material also differ from the specified design strength. Therefore strength of material is also considered as a random variable. Variation of material strength may be approximated by a frequency curve as shown in the figure below.



- R_k is the characteristic strength value whereas R_m is the mean value. Shaded area represents the probability of occurrence of strength values less than R_k .

Similar to equation 0.1 the following equation can be given for R_k :

$$R_k = R_m - u \cdot \sigma_R \quad (0.2)$$

where σ_R is standard deviation for R .

σ_R depends on the degree of supervision and inspection of production. $u=1.28$ in Turkey. For the safety of structure $R_k \geq P_k$ if R_k and P_k are selected as design values.

In the figure below this situation is shown where double shaded area represents the probability of failure.

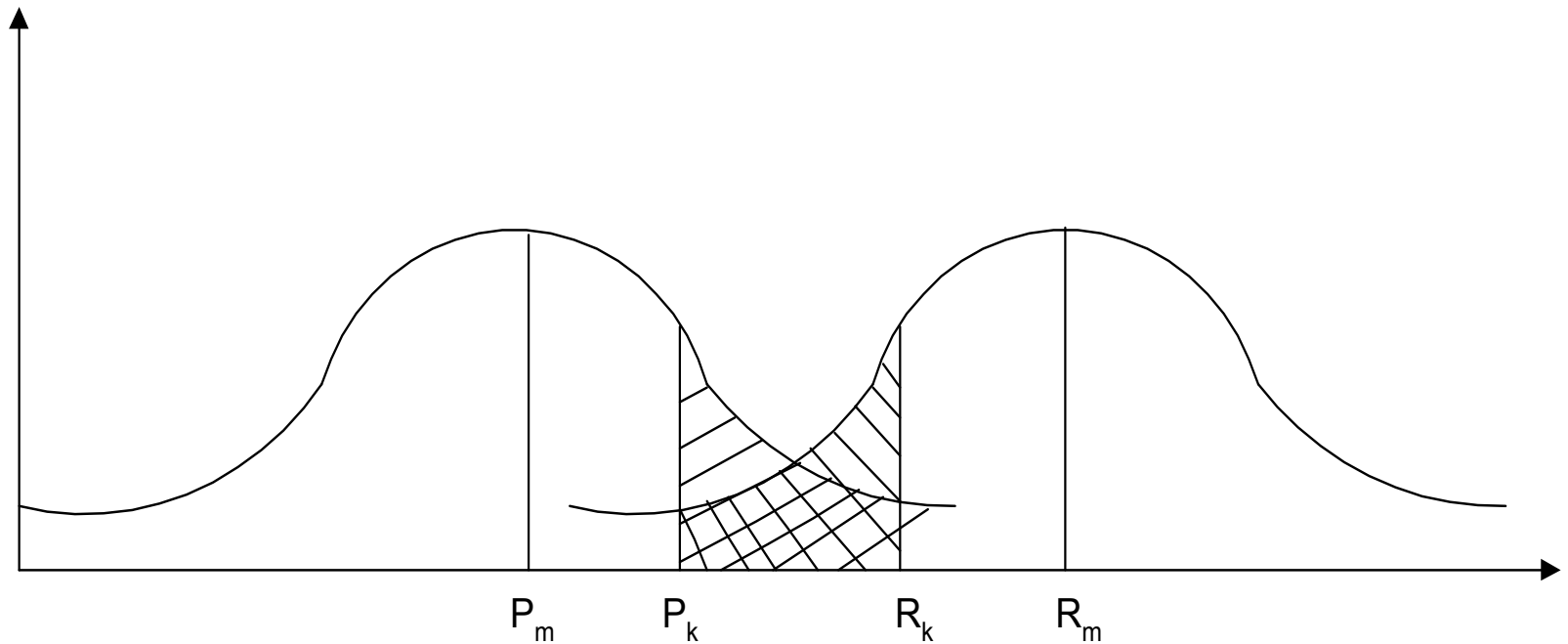


FIG. 1.7

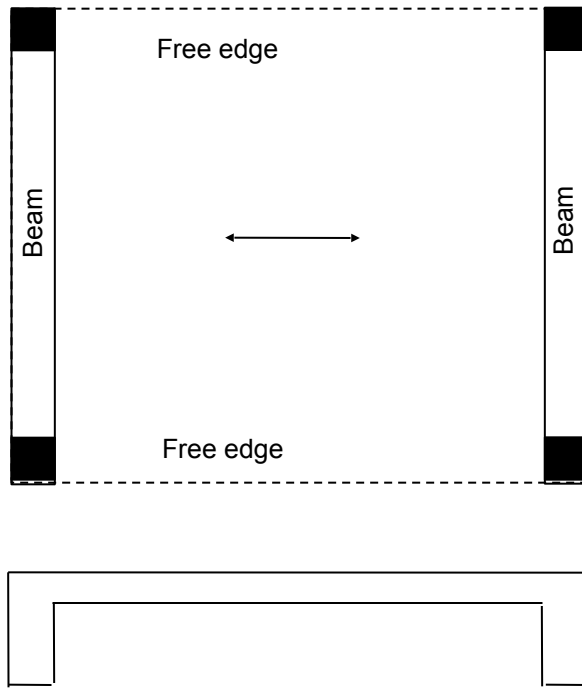
- Statistical calculation shows that the probability of failure is rather high if R_k and P_k are used as design values. Hundred percent safety is not possible but probability of failure can be reduced by increasing the design value of load and decreasing the strength value. This can be achieved by using appropriate factors. Dividing R_k by a factor greater than 1 and multiplying P_k by a factor greater than 1 design values are obtained. Considering economic results of collapses it is tried to achieve a probability of failure as small as 10^{-5} - 10^{-7} .

CHAPTER I

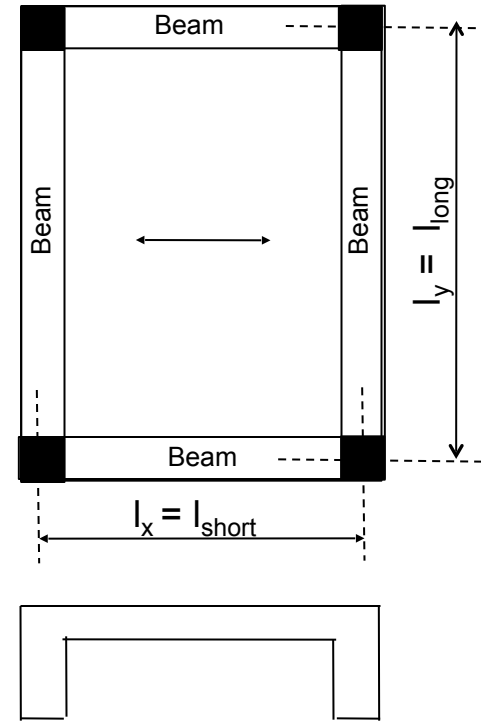
EDGE-SUPPORTED SLABS

1.1 INTRODUCTION

- Floors and roofs of reinforced concrete buildings are called slabs.
- Slabs are assumed as two-dimensional members since their third dimension (height) is rather small.
- Slabs are usually cast monolithically with the supporting beams or columns.
- In addition to reinforced concrete framed structures RC slabs can also be used in masonry or steel structures.
- Supports of RC slabs are either beams or load bearing walls or columns.
- Slabs are usually supported at the four edges but some of them may be supported at three, two or even one edge.
- Loads on slabs are assumed to be uniformly distributed except in some extraordinary cases which may require special treatment



a) One-way slab



b) One-way slab
($l_y / l_x > 2$)

Figure 1.1

The simplest type of edge supported slabs is shown in Fig.1.1a. This kind of slabs are supported by beams as shown in the figure or by load bearing walls at only two opposite edges. The other two edges are free, that is having no supports at all. They bend cylindrically between two supported edges. This behavior shows that they carry the loads in only one direction as shown by arrows in the figure. Therefore slabs of this kind are called one-way slabs. A very similar behavior is observed in the slabs supported at four edges, if they are long and narrow. In Fig.1.1b such a slab is shown. These kinds of slabs also are called one-way slabs.

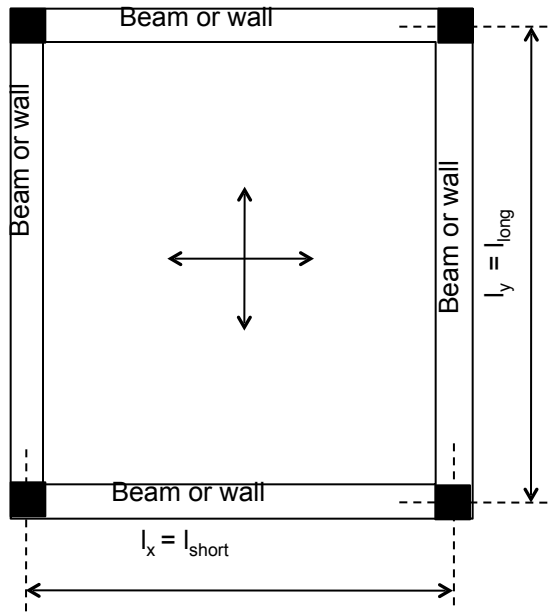


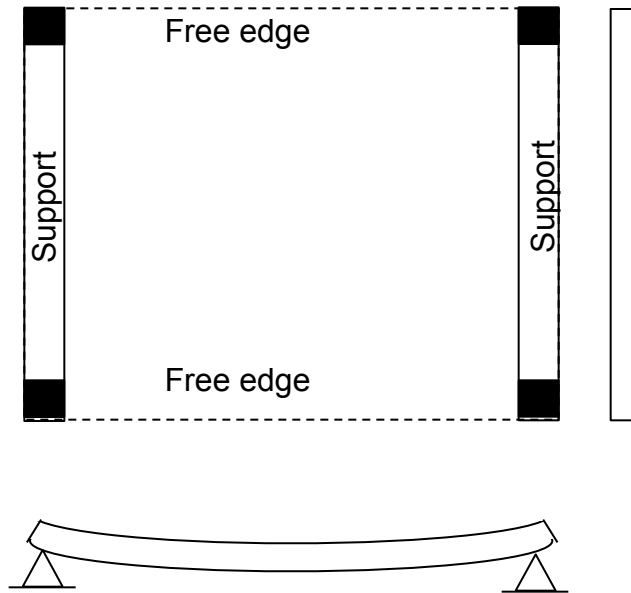
Figure 1.2 Two-way slab
 $(l_y / l_x \leq 2)$

Slabs supported at four edges bend in all directions if the ratios of long spans to short spans are not greater than two. Although they bend in all directions it is sufficient to consider bending in two principle directions. Such a slab which is called two-way slab is shown in Fig.1.2. A slab supported at only two opposite sides is definitely a one-way slab regardless of the ratio of the two span lengths, while a slab which is supported at the four edges is theoretically a two-way slab. In two-way slabs bending in the long direction is less than bending in the short direction. As the ratio of long span to short span increases bending in the long direction becomes less and less significant. If this ratio is higher than two bending in the long direction can be neglected. Therefore it is common practice to use a limit value of 2 for the definition of one-way and two-way slabs. Slabs with $l_y / l_x > 2$ are called one-way slabs, while the ones with $l_y / l_x \leq 2$ are called two-way slabs.

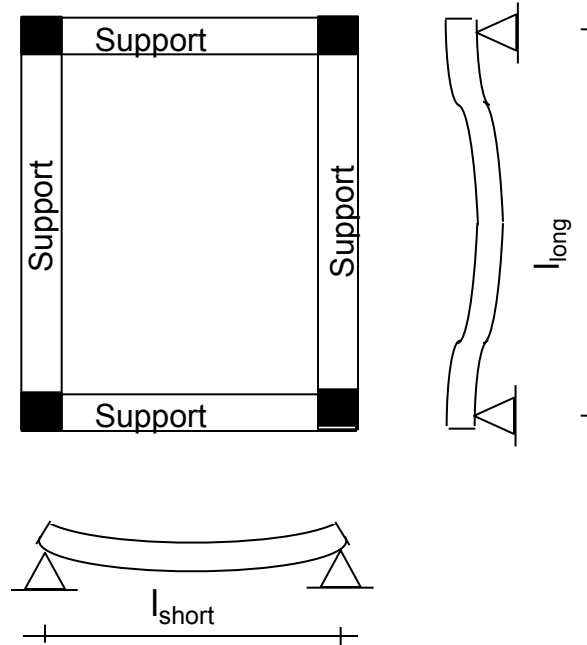
Floors of the buildings are normally constructed by continuous systems of slabs. Floors may be of only one-way or only two-way solid slabs or of two types. In some buildings it may be convenient to use other kind of slabs, such as joist slabs in certain parts of the floor while other parts are made of solid slabs.

As mentioned earlier heavy concentrated loads complicate the analysis therefore need special treatment, and it is preferred to support them directly by beams. For example instead of erecting a heavy wall directly on the slab it is better to provide a beam just under the wall.

1.2 ONE-WAY SLABS



a) Slab supported at two opposite edges



b) Slab supported at four edges
($l_{long} / l_{short} > 2$)

Figure 1.3

In Fig.1.3a bending of a one-way slab supported at two opposite edges is shown. This is a completely cylindrical bending between the supports. There is no bending at all in the other direction. The slab shown in Fig.1.3b is supported at the four edges but the ratio of the span lengths is greater than two. In this kind of slabs bending is essentially in the short direction. Bending in the long direction is very small except in the areas very close to the short edges. This behavior of one-way slabs shows that all the loads are carried in one direction just like the beams. Therefore, one-way slabs may be considered as very wide beams. Alternatively it can be assumed that a one-way slab is formed by casting and putting side by side a number of shallow beams. Actually this is one of the methods when precast slabs are constructed. It is obvious now that we can analyze and design only a strip of the slab. Since all the other strips with the equal width are identical, the same reinforcement is used in every strip. For the structural analysis any method developed for elastic beams can be used. In continuous systems live loads should be located in a way to generate most unfavorable internal forces.

It is very convenient to take one meter wide strips. Thus they can be designed as one meter wide beams. In one-way slabs the reinforcement calculated and selected to resist the bending moment is called main reinforcement. In the design of slabs it is common practice to determine the spacing of the bars rather than the number of the bars. This kind of information is very convenient during placement of the bars. Spacing of the bars can easily be calculated. For example, let us assume that 6.83 cm^2 steel is needed for a 100 cm wide strip and $\text{Ø}10$ bars are to be used. Since the area of one $\text{Ø}10$ bar is 0.79 cm^2 $6.83/0.79 = 8.65$ bars are necessary for this strip. Corresponding spacing will be $100/8.65 = 11.5 \text{ cm}$. To make the design easier special steel area tables are prepared for slab design. They give steel areas for a number of combinations of various diameter bars and spacing (Table 1.1).

Although one-way slabs bend only in one direction it is necessary to provide reinforcement in the other direction as well. This reinforcement which is called **distribution steel controls the shrinkage and the temperature cracks**. These bars also take the tensile forces caused by any bending moment in the long direction. They are placed over the main steel.

It is shown in Fig.1.3b that one-way slabs bend in the long direction in the vicinity of the short supports. This bending is associated with negative support moments. Therefore top steel parallel to the distribution steel is required at the supports to prevent the cracking.

- **PROVISIONS OF TS 500 FOR ONE-WAY SLABS**

Thickness of one-way slab can not be **less than 8 cm**. However roof slabs may be **6 cm thick**. On the other hand, minimum thickness for the **slabs subjected to traffic loads, is 12 cm**. Besides, the thickness of one-way slabs can not be the less than the following values.

$$\frac{l_n}{25} \quad \text{in simply support single spans}$$

$$\frac{l_n}{30} \quad \text{in continuous slabs}$$

$$\frac{l_n}{12} \quad \text{in cantilever slabs}$$

where **ln** is the clear span length.

Minimum ratio for main steel is
0.003 if steel is S220,
0.002 if steel is S420 or S500.

The lateral spacing of the bars should not be more than 1.5 times the thickness "h" and 20 cm. In single span slabs at least half of the bars, in continuous slabs at least one third of the bars should be straight bars extending from support to support.

The area of the distribution steel should be at least $\frac{1}{5}$ of the main steel area in that span. However spacing of the distribution steel should not be more than 30 cm.

The area of support bars in the long direction should not be less than 0.6 times the main steel area in the same span. Besides they should not be less than $\text{Ø}8/20$ cm if S220 steel is used, $\text{Ø}8/30$ cm if S420 steel is used and $\text{Ø}5/15$ cm if S500 steel is used.

Extension length of the straight parts of these top bars should be at least $1/4$ of short clear span length.

All reinforcing bars must be properly anchored. Development lengths of the bars in the supports measured from the face of the support should be at least 15 cm. The clear concrete cover protecting the reinforcement should not be less than 1.5 cm.

In one-way slabs distribution steel bars are always straight bars whereas main steel bars are usually half straight and half bent-up bars where bent-up bars are placed at the middle of straight bars. Bent-up bars provide **reinforcement both for the positive moments at the spans** and for the **negative moments at the supports**. In continuous slabs two of every three bars can be bent-up for the purpose of increasing the reinforcement at the supports. On the other hand, all bars of the main steel may be straight especially if hard steel such as S420 is used. In slab drawings one bar is shown if all bars are straight, one straight and one bent-up bar are shown if half straight and half bent-up bars are used. A typical one-way slab drawing is shown in Fig.1.4.

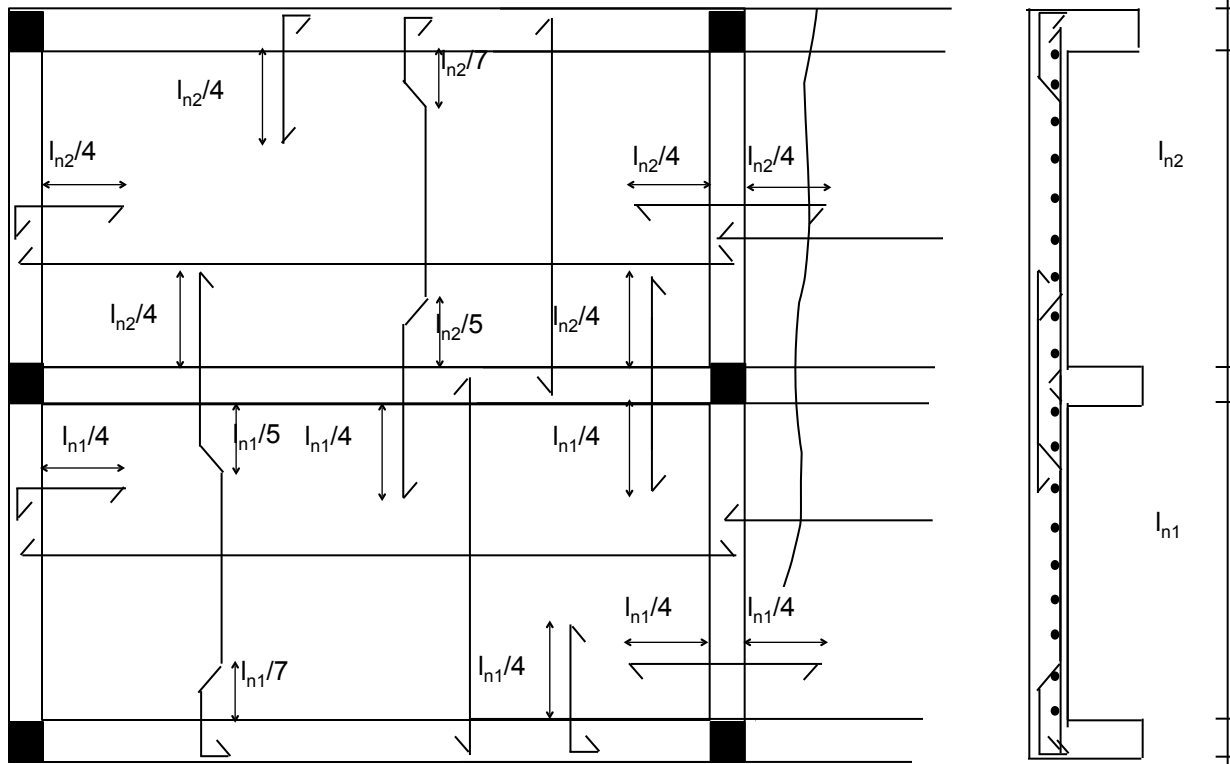


Figure 1.4

In the supports available reinforcement provided by bent bars may not be as much as required reinforcement. In that case additional support reinforcement is placed as shown in Fig.1.4. In Fig.1.5 alternative forms of support bars are shown. They can keep their position better than the straight bars during the casting of concrete. Reinforcement at the external supports should not be less than half of the main steel at the same span.



Figure 1.5

TABLE 1.1 STEEL AREAS FOR 100 CM WIDTH OF SLABS, CM²

<i>s (cm)</i>	Φ 6	Φ 8	Φ 10	Φ 12	Φ 14	Φ 16	Φ 18	Φ 20	Φ 22	Φ 24
7.0	4.04	7.18	11.22	16.16	21.99	28.73	36.36	44.87	54.30	64.63
7.5	3.77	6.70	10.47	15.08	20.52	26.81	33.93	46.88	50.81	60.32
8.0	3.53	6.28	9.82	14.14	19.24	25.14	31.81	39.26	47.51	56.55
8.5	3.33	5.91	9.24	13.31	18.11	23.66	29.94	36.95	44.72	53.22
9.0	3.14	5.59	8.73	12.57	17.10	22.34	28.28	34.90	42.23	50.27
9.5	2.98	5.29	8.27	11.90	16.20	21.17	26.79	33.06	40.01	47.62
10.0	2.83	5.03	7.85	11.31	15.39	20.11	25.45	31.41	38.01	45.24
10.5	2.69	4.79	7.48	10.77	14.66	19.15	24.24	29.91	36.20	43.09
11.0	2.57	4.57	7.14	10.28	13.99	18.28	23.14	28.55	34.55	41.13
11.5	2.46	4.37	6.83	9.84	13.39	17.49	22.13	27.31	33.05	39.34
12.0	2.36	4.19	6.54	9.42	12.83	16.76	21.21	26.17	31.67	37.70
12.5	2.26	4.02	6.28	9.05	12.32	16.09	20.36	25.13	30.41	36.19
13.0	2.17	3.87	6.04	8.70	11.84	15.47	19.58	24.16	29.24	34.80
13.5	2.09	3.72	5.82	8.38	11.40	14.90	18.85	23.27	28.16	33.50
14.0	2.02	3.59	5.61	8.08	11.00	14.36	18.18	22.44	27.15	32.31
14.5	1.95	3.47	5.42	7.80	10.62	13.87	17.55	21.66	26.21	31.20
15.0	1.89	3.35	5.24	7.54	10.26	13.41	16.97	20.94	25.34	30.16
15.5	1.82	3.24	5.07	7.30	9.93	12.97	16.42	20.27	24.52	29.19
16.0	1.77	3.14	4.91	7.07	9.62	12.57	15.90	19.64	23.76	28.28
16.5	1.71	3.05	4.76	6.85	9.33	12.19	15.42	19.04	23.04	27.41
17.0	1.66	2.96	4.62	6.65	9.05	11.83	14.97	18.48	22.36	26.61
17.5	1.62	2.87	4.49	6.46	8.79	11.49	14.54	17.95	21.72	25.85
18.0	1.57	2.79	4.36	6.28	8.55	11.17	14.14	17.46	21.12	25.13
18.5	1.53	2.72	4.25	6.11	8.32	10.87	13.76	16.94	20.55	24.45
19.0	1.49	2.65	4.13	5.95	8.10	10.58	13.39	16.56	20.01	23.81
19.5	1.45	2.58	4.03	5.80	7.89	10.31	13.05	16.11	19.49	23.20
20.0	1.41	2.51	3.93	5.65	7.69	10.05	12.72	15.72	19.01	22.62