CHAPTER 2

THEORETICAL BASIS

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2.1 PREVIOUS RESEARCH AND RESEARCH DIFFERENCES

2.1.1 Previous Research

In this thesis, the compiler examines existing or previously conducted research with similar case studies regarding analysis and design as research reference material. The selection of research references that have been carried out previously must be in accordance with the discussion studied for the thesis. The assessment of the research that has been previously studied is useful to find out how the research methods and the results are used as a benchmark for researchers in compiling and analyzing a study.

Below are some of the references to previous research studied, including:

1. Planning analysis conducted by Sri Kurniawati Panjaitan (2021). Thesis Title **"Analisis Struktur Bangunan Bertingkat Menggunakan Etabs (Studi Kasus RS. Regina Maris Medan)".** This study aims to calculate the structure of the building using the ETABS V.18.1.1 program based on SNI 2847: 2019 and compare it with those in the field.
2. Planning analysis conducted by Sukma Idham Laksana (2021). The title of the thesis is **"Perencanaan Ulang Bangunan Bertingkat Beton Bertulang Tahan Gempa Menggunakan Sistem Ganda (SRPMK Dan Dinding Struktural Khusus) Berdasarkan SNI 1726:2019 Dan SNI 2847:2019 (Studi Kasus: Gedung Laboratorium Vokasi dan Industri Kreatif Vokasi Kampus II UB Malang)".** This study aims to re-plan high-rise buildings using a Special Moment Bearing Frame Dual System (SPRMK) and a Shear

Wall structure (Sheer Wall) that meets the requirements for structural safety.

Table 2.1 Literary Studies

No.	Researchers	Year	Research Title
1.	Sri Kurniawati Panjaitan	2021	Analisis Struktur Bangunan Bertingkat Menggunakan Etabs (Studi Kasus Rumah Sakit Regina Maris Medan).
2.	Sukma Idham Laksana	2021	Perencanaan Ulang Bangunan Bertingkat Beton Bertulang Tahan Gempa Menggunakan Sistem Ganda (SRPMK dan Dinding Struktural Khusus) Berdasarkan SNI 1726:2019 dan SNI 2847:2019 (Studi Kasus: Gedung Laboratorium Vokasi dan Industri Kreatif Vokasi Kampus II UB Malang).

2.1.2 Research Differences

Basically, the research carried out today has similar elements of research with those that have been done before. Based on its purpose is to design buildings using reinforced concrete structures.

The research in this thesis is to design and analyze the structure of the laboratory building of Swadaya Gunung Jati Cirebon University using:

1. SNI 1727:2020 - Minimum design load and related criteria for buildings and other buildings.
2. SNI 2847:2019 - Structural Concrete Requirements for Buildings.
3. SNI 1726:2019 - Earthquake Resistance Planning Procedures for Building and Non-Building Structures.

The difference between the previous research and the research currently carried out lies in the location of the study, the type of building planned, the purpose of the study, and the method of analyzing structural calculations, where in this study used two calculation analyses, namely using manual calculations and using ETABS which is one of the structural analysis software, then the researcher also calculated the cost budget plan for the needs of the laboratory building structure which designed.

2.2 REINFORCED CONCRETE STRUCTURE

Reinforced concrete is the dominant material used in the world of building construction compared to other materials such as steel and wood. Concrete materials are easy to get. Concrete is a composite material consisting of cement, water and aggregate. The concrete hardens due to a chemical reaction that occurs between portland cement and water. Concrete technology has developed rapidly in the last three decades. The need for quality, high-use materials, having a long service life and being resistant to weather changes has become the main goal for the development of concrete technology in this modern era. The quality or quality of concrete is expressed from the compressive strength of the concrete $(f'c)$ possessed. (Antonius, 2021 : 1)

The use of reinforced concrete in structures is already very wide, such as for residential buildings, buildings, bridges, stadiums, road pavements, dams, earth retaining walls, tunnels, bridges that cross valleys (viaducts), drainage and irrigation facilities, water tanks, and so on. (Antonius, 2021 : 2)

One of the advantages of concrete material in the structure is in its manufacture which is easy to form according to architecture so that it looks more aesthetically pleasing. In its widespread and diverse use, reinforced concrete structures have developed into a science that is very prominent in the field of civil engineering. Until now, various researches on reinforced concrete, both analytical / numerical and experimental such as bending behavior, shear, torque, the influence of axial loads, dynamic behavior of structures (including earthquake-resistant structures) continue to be carried out, both in Indonesia and in various other countries. In Indonesia, the implementation and design guidelines of reinforced concrete structures are also constantly undergoing changes, and the latest is currently stated in the standard, namely concrete structure requirements for buildings or SNI-2847-2019. (Antonius, 2021 : 3)

SNI 03-2847-2019 Article 3.7.2 defines prestressed and non-prestressed concrete with the use of reinforcing steel that meets the minimum repeating requirements and is designed on the assumption that the two materials work as a single unit to withstand the working forces. The main property of concrete, which is that it is very strong against compressive loads, but it is also brittle / easily broken or damaged to tensile loads. From these main properties, then if the two materials are combined into a composite unit, a new material called reinforced concrete will be obtained. (Iksan, Budiono and Wiratna, 2020)

The advantages of reinforced concrete, include:

- Can follow the shape of the building freely.
- Almost no maintenance
- Resistant to earthquakes
- Resistant to rust
- Smaller size when compared to spineless concrete or masonry.
- As the ground floor/foundation on poor/loamy soil is very good.
- Absorbs/Tolerates sound.

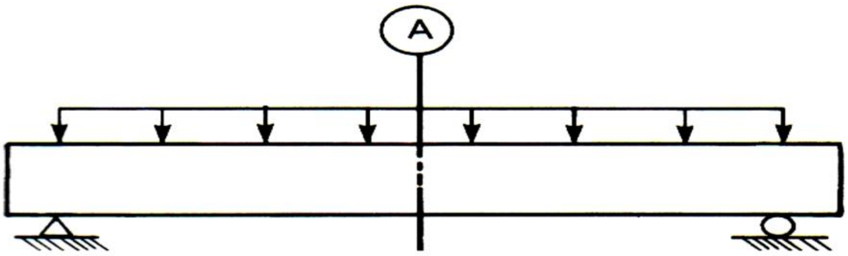
The disadvantages of reinforced concrete, include:

- The quality of concrete depends on the material and its execution.
- Cannot be disassembled/moved.
- Disassembly cannot be reused.
- Large construction weight when compared to wood/steel construction.

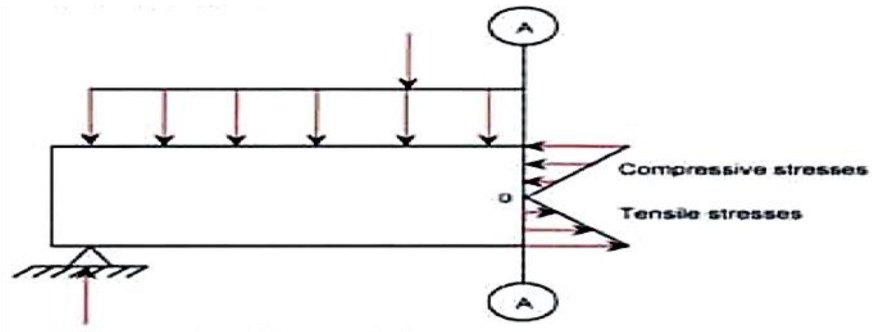
(Iksan et al., 2020)

2.3 BASIC PRINCIPLES OF REINFORCED CONCRETE

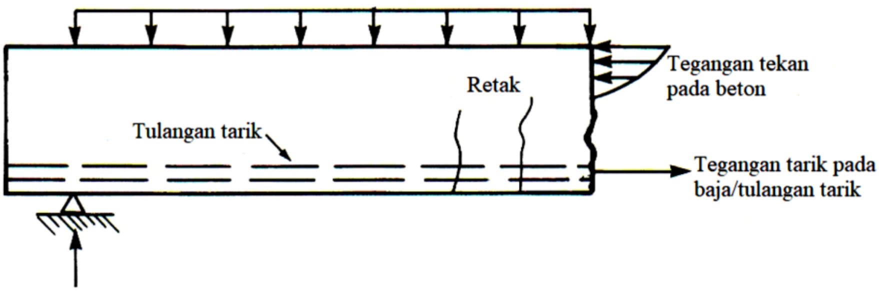
According to Antonius (2021: 4) Mechanically concrete is a material that is strong in resisting pressure, but weak in resisting tensile. Therefore, concrete can be subject to cracking if the load it carries gives rise to tensile stresses that exceed its tensile strength. The stress mechanism that causes the use of steel reinforcement in concrete so that a reinforced concrete structure is formed can be illustrated as figure 2.1. Figure 2.1a shows a beam that is evenly divided. In a concrete block structure without reinforcement (figure 2.1b), the moment arising from the outer load (in this case the load is evenly divided) will cause compressive and tensile stresses so that compressive stresses and tensile stresses occur in cross section.



(a) Concrete Blocks with Evenly Divided Load



(b) Tension Mechanism of Unbarred Concrete Blocks



(c) Tension Mechanism of Unbarred Concrete Blocks

Figure 2.1 Voltage Mechanism on Beams (Mac Gregor, 1997)

As already mentioned above that since concrete is very weak in resisting tensile, then in the zone of attraction the cross section of such concrete blocks can experience a sudden collapse. In reinforced concrete blocks (figure 2.1c), reinforcing bars are planted in the concrete in such a way as to form a composite structure between concrete and steel reinforcement, so that the tensile force needed to withstand the moment in cross-section of the crack can be developed on the steel reinforcement. (Antonius, 2021 : 5)

To overcome the weakness of concrete in resisting tensile, steel reinforcement is added to the cross-section of concrete that has the potential to experience tensile when withstanding loads. The role of steel reinforcement in resisting tensile is very useful because steel has a very high tensile stress and tensile strain and is daktail. (Antonius, 2021 : 5)

2.4 COMPONENTS OF REINFORCED CONCRETE STRUCTURE

Reinforced concrete structures consist of several of their forming components that interact with each other to form a single unit of structure. Some of the components of reinforced concrete structures encountered include:

1. Slabs
2. Columns
3. Beams
4. Walls
5. Stairs
6. Foundation and etc.

In the analysis of the structure of the components of the structure, it can be modeled in such a way that it is a portal in three dimensions, so that the identification of the components of the structure can be done easily. (Antonius, 2021:5)

2.5 STRUCTURAL ANALYSIS FOR REINFORCED CONCRETE DESIGN

Basically, the design of reinforced concrete is to determine the dimensions of each element of the structure such as slabs, beams, columns in order to obtain the dimensions of the concrete, the diameter and the number of reinforcement as efficiently as possible. The amount of these dimensions is based on the factored loading flow that the structure will receive, which is then carried out structural analysis. As usual, in the analysis of the structure will be produced internal forces or imbulent reactions. These inner styles are used as the main reference in the design of reinforced concrete. Figure 2.2 is a two-dimensional form of a specific static portal building. (Antony, 2021:7)

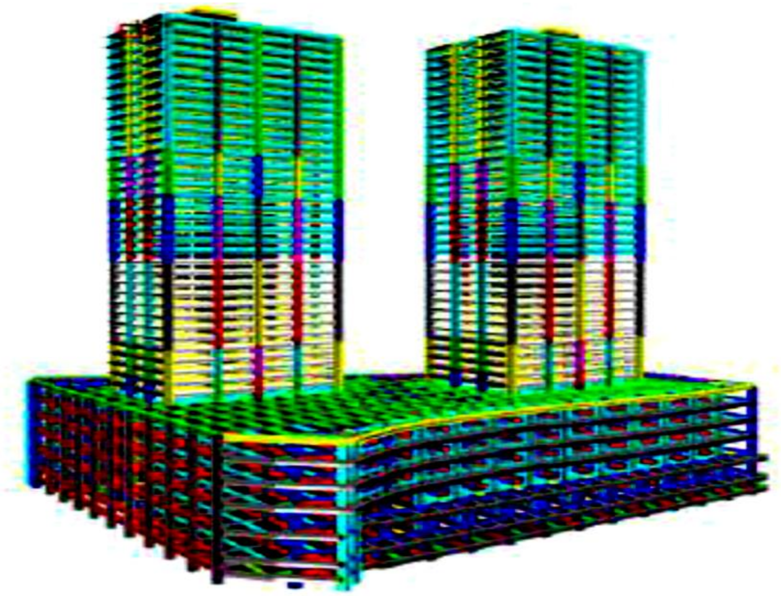
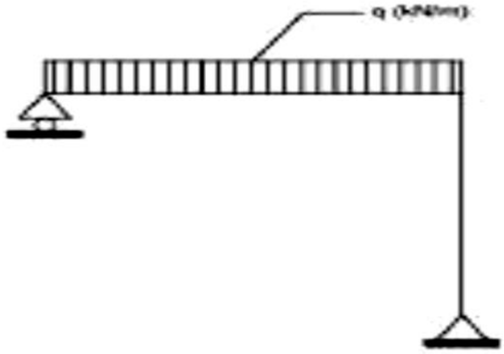


Figure 2.2 Modeling of Three-Dimensional Concrete Structures In High-rise Buildings (40 Floors)
(Antonius, 2021 : 7)

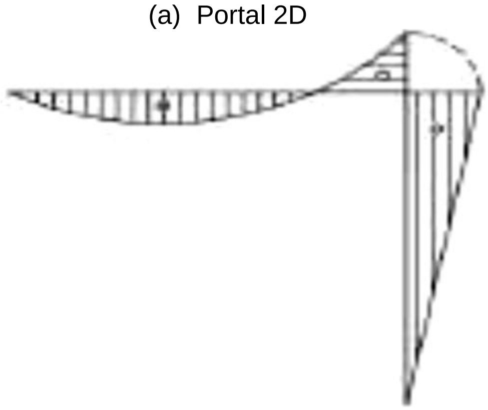
As a result of the static load acting on such buildings will be obtained:

- Moment diagram (M)
- Shear force (field D) and,
- Axial force (N).

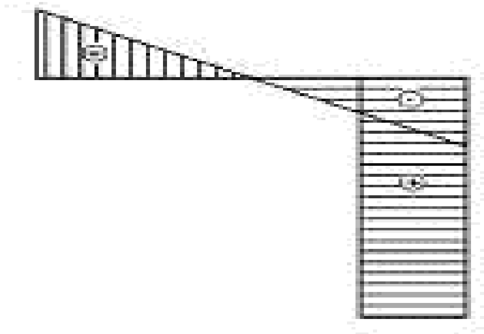
The magnitude of the moment that occurs will determine the cross-sectional dimensions of concrete and the need for flexible reinforcement, namely longitudinal reinforcement on columns, beams and slabs. The working shear force will be used in determining the shear reinforcement or often also called the shear reinforcement on the beam. Diagrams of axial forces or normal planes will be decisive in the design of the elements of the column structure. An example of the components of the structure to which longitudinal reinforcement and shear reinforcement are installed is shown in figure 2.3. In addition to these three diagrams, it is also necessary to take into account the possibility of torque / twisting on the beam. (Antonius, 2021 : 7)



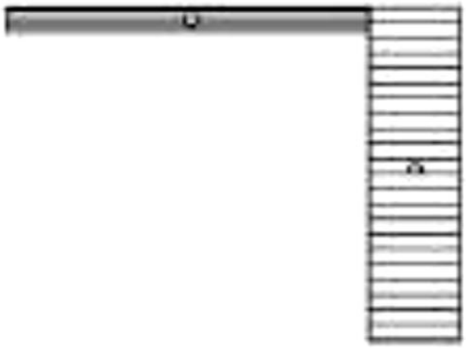
(a) Portal 2D



(b) Moment Field Diagram (M) (M)



(c) Shear Field Diagram (D)



(d) Normal Field Diagram (N)

Figure 2.3 2D Portal Structure with Inner Style Diagram
(Antonius, 2021 : 8)

2.6 PLANNING CONCEPT

The designed structure must basically meet several criteria such as compliance with the surrounding environment, economical, strong in withstanding planned loads, meet service capability requirements, easy to maintain (high durability) and sustainable. (Antonius, 2021 : 9)

In the design procedure for strength, the level of safety is determined by various combinations of load factors and Ï• strength reduction imposed on nominal strength. Currently there are two philosophies in planning elements of reinforced concrete structures, namely:

2.6.1 Working Voltage Method

Structural elements are planned against the workload in such a way that the voltage occurring is smaller than the allowable voltage, wherein:

$$\sigma \leq \overline{\sigma}$$

2.6.2 Ultimit Strength Method

With this method, the elements of the structure are planned against the desired ultimit strength load, namely:

$$M_u \leq \phi M_n$$

According to Antonius (2021) in the planning of reinforced concrete elements, there are several boundary conditions that can be used as guidelines, namely:

- Ultimite boundary conditions can be caused by several factors such as loss of local or global equilibrium, rupture, namely loss of bending and shear resistance of structural elements, progressive collapse due to local collapse in the surrounding area, formation of plastic joints, structural instability and fatigue.
- Service capability limit conditions that concern reduced structural functioning, such as excessive deflection under service conditions, excessive crack width and disruptive vibration.
- Special limit conditions, which concern damage/collapse due to abnormal loads, such as collapse in conditions of extreme earthquakes, fires, explosions or collisions of vehicles and corrosion or other types of environmental damage.

Planning that pays attention to the conditions of the boundaries above is called boundary planning. This boundary planning concept is used as the basic principle of the Indonesian Concrete Regulation (SNI-2847-2019). (Antonius, 2021 : 10)

2.7 DESIGN BASED ON INDONESIA CONCRETE STANDARD (SNI-2847:2019)

Structural analysis is essentially in order to determine the "strength demand" of a structure with a certain load. The product of structural analysis is internal forces, namely latitude, moment and axial forces and "joint displacement" in horizontal and vertical directions as shown in the figure above. For relatively rigid structures, for example reinforced concrete structures in medium buildings (< 20 levels), what generally determines is the internal forces. As for slim buildings, the deflection is likely to determine the count. (Antonius, 2021 : 10)

Structural elements and structures must always be designed to be able to carry overloads of a certain magnitude, beyond the loads that are expected to occur under normal conditions. Such spare capacity is needed to anticipate the possible presence of "overload" factors and "overcapacity" factors. (Antonius, 2021 : 10)

Overload can occur as a result of:

- Changes in the functioning of the structure
- Underestimate the effect of the load due to simplification of calculations
- Construction sequences and methods

Undercapacity can occur as a result of:

- Variations in material strength
- Workmanship
- Level of oversight

Based on Antonius (2021: 11) If the structural analysis is in order to determine the strength demand, then the design of the element is in order to determine supply. Based on the standard design procedure, the strength (resistance) of the elements of the structure must be greater than the influence of the load. The basic requirements for the strength of the plan are determined by the following equation:

The power of the plan ≥ The power is necessary, which can be written (SNI 2847-2019 article 4.6):

$$\phi S_n \geq U$$

In order to anticipate the possibility of lower resistance (strength) of structural elements than is taken into account / planned and the possibility of greater influence of the load than planned, a force reduction factor is introduced, whose value is <1, and a load factor whose value is >1, so that:

$$\boldsymbol{\emptyset Sn} \geq \boldsymbol{\alpha_1 U_1} + \boldsymbol{\alpha_2 U_2} + \boldsymbol{....}$$

where:

Sn = Nominal Strength

U = Load Influence

∅ = Reduction Factor

a_i = Load Factor

The design procedure that takes into account the presence of the above load and resistance factors is referred to as the ultimit strength design. This design procedure is basically a method of planning boundary conditions where the main attention is emphasized on the ultimit boundary conditions. The serviceability limit condition (service capability) is then checked after the initial design is obtained. (Antonius, 2021 : 11)

2.8 LOAD FACTORS AND THEIR COMBINATIONS

In structural loading planning, several standard references are used, including:

1. SNI 2847:2019 as an earthquake resistance planning standard for building structures
2. SNI 1727:2020 as a guideline for planning the minimum load on the building which includes:
   - Burden of Life
   - Dead Load
   - Wind Load
   - Earthquake Load

2.8.1 Dead Load (DL)

Pursuant to PPIUG 1983 article 1.1 A dead load is the weight of all parts of a building that are fixed, including all additional elements, machinery, as well as fixed equipment that is an indispensable part of the building.

2.8.2 Live Load (LL)

Based on PPIUG 1983 article 1.2 Live load is all loads that occur due to the occupancy or use of a building, and all equipment in it including loads on the floor that come from movable goods, machinery and equipment that are not an integral part of the building and can be replaced during the operating period of the building, resulting in changes in the loading of the floor and roof. Especially on the roof, rainwater is a component of living loads, both due to inundation and due to falling pressure (kinetic energy) of water droplets.

2.8.3 Wind Load (W)

Based on PPIUG 1983 article 1.3 Wind load is all loads acting on a Building or part of a Building caused by a difference in air pressure.

2.8.4 Earthquake Load (Eq)

Based on the 1983 PPIUG article 1.4 Earthquake load is all equivalent static loads that work on a building or part of a building that mimics the influence of soil movement due to the earthquake, then what is interpreted by an earthquake here is the forces in the structure that occur by soil movement due to an earthquake.

2.8.5 Load Combination

According to SNI 2847:2019 article 5.3.1 The force needs to be U expressed in the forms of factored loads, moments and related inner forces. Factored loads are those that are established by the applicable loading regulations, then multiplied by the corresponding load factors.

Table 2.2 Load Combination

Kombinasi beban	Persamaan	Beban utama
$U = 1{,}4D$	(5.3.1a)	D
$U = 1{,}2D + 1{,}6L + 0{,}5(L_r$ atau $R)$	(5.3.1b)	L
$U = 1{,}2D + 1{,}6(L_r$ atau $R) + (1{,}0L$ atau $0{,}5W)$	(5.3.1c)	L_r atau R
$U = 1{,}2D + 1{,}0W + 1{,}0L + 0{,}5(L_r$ atau $R)$	(5.3.1d)	W
$U = 1{,}2D + 1{,}0E + 1{,}0L$	(5.3.1e)	E
$U = 0{,}9D + 1{,}0W$	(5.3.1f)	W
$U = 0{,}9D + 1{,}0E$	(5.3.1g)	E

Source: Table 5.3.1 SNI 2847:2019

According to Antonius (2021) E is determined based on SNI 1726:2019 (Earthquake Resistance Planning Procedures for Houses and Buildings). The strength of the need or influence of the reactor load (such as moment, shear, torque and axial force) is calculated based on the combination of the above U-factored loads. The strong need or influences of the factored load are written with the symbols of $Mu, Vu, Tu\ and\ u$. The subscript u indicates that those values of $M, V, T\ and\ u$ are obtained from the factorized load U.

2.9 REDUCTION FACTOR

According to Antonius (2021 : 12) Strong plan of a structural component (ϕR_n) obtained by multiplying the nominal power R_n with strength reduction factor ϕ. Based on MacGregor (1997), the function of the force reduction factor ϕ are:

- To estimate the possibility of insufficient cross-sectional strength (under-strength) due to differences in dimensions and strength of the material;
- To estimate inaccuracies at the design stage;
- To express the value of ductility and the required level of resistance relative to the load;

- To express how vital the cross section is relative to the overall structure.

Based on SNI 2847:2019 article 21, the value of the force reduction factor (ϕ) non-prestressed concrete is as follows:

(1) Tensile Controlled Cross-Section = 0,90.

SNI 2847:2019 article 10.3.4 explains, the cross section is said to be tensile-controlled if the tensile strain of concrete in the farthest tensile steel, εt is equal to or greater than 0.005 when the compressed concrete reaches the assuming strain limit of 0.003. Cross section with εt between the compressive controlled strain boundary and 0.005 forms a transitional region between the compressive controlled and tensile-controlled cross-sections.

(2) Compressive Controlled Cross-Section

(a) Components of structures with spiral reinforcement = 0,75.

Furthermore, SNI 2847:2019 article 21.2.2.2 explains that for cross-section where the net tensile strain in the steel is the farthest tensile at the nominal strength εt, being in the obvious limits for a controlled cross section of compressive and controlled tensile, then Ø can be linearly increased from the value for a compressive controlled cross-section to 0.90 as it increases εt from a compressive controlled strain limit to 0.005 (Figure 2.4). Compressive controlled type columns are limited to a maximum tensile replay strain of $0.002\ or\ a\ ratio\ of\ c/d = 0{,}6$. For tensile-controlled type columns, the minimum tensile reinforcement strain is $0.005\ or\ c/d = 0.375$. Among the two types of control are transition areas, where the values of the reduction factors are as follows:

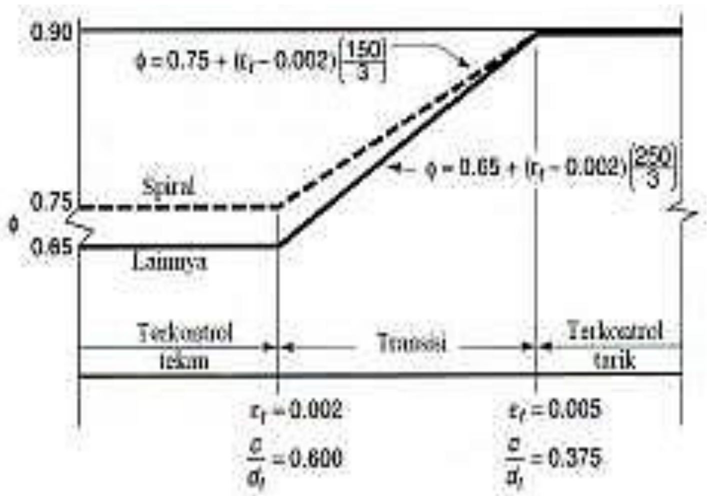


Figure 2.4 Variations in values Ø net tensile strain on the farthest tensile reinforcement εt.

In Figure 2.4, in the transition area:

For spirals:

$$\Phi = 0.75 + 0.15\left[\frac{1}{c-d} - \frac{5}{3}\right]$$

For non-spiral:

$$\Phi = 0.65 + 0.25\left[\frac{1}{c-d} - \frac{5}{3}\right]$$

(b) Structural components with other reinforcement = 0,65

For axial compressive and qualified component the following conditions $fy \leq 400\,MPa$, reinforcement is symmetrical, and $(h - d' - ds)/h \geq 0{,}70$. Then the value of Ø boleh ditingkatkan secara linear menjadi 0,90 for value $\emptyset Pn$ which is reduced from $0{,}1fc'Ag$ ke nol.

For other components of the structure, the value Ø can be linearly increased to $0{,}90$ for value $\emptyset Pn$ which is reduced from $0{,}1fc'Ag$ or $\emptyset Pb$ (take the value of the smallest) to zero. (Antonius, 2021)

(3) Shear and Torque 0,75

(4) The Fulcrum on Concrete Where:

d’ = The distance from the fibers of the farthest press to the centroid of the compressive reinforcement.

ds = The distance from the farthest tensile fiber to the centroid of the tensile reinforcement.

h = Height of total cross-section.

Pn = Nominal axial load strength for a given value of eccentricity.

Pb = Nominal axial load strength under balanced conditions.

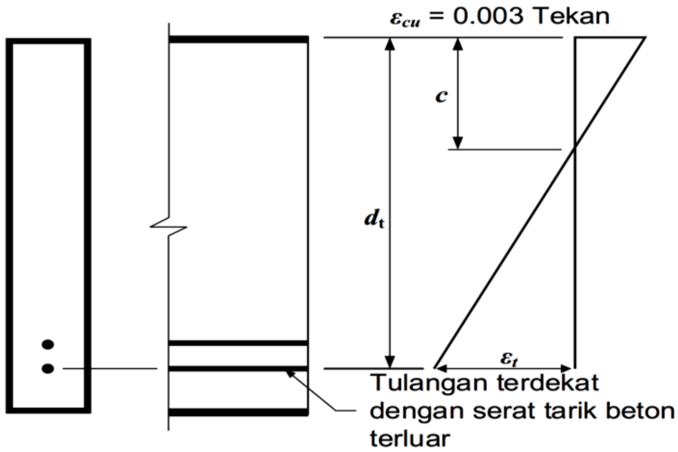


Figure 2.5 Strain Distribution on Concrete Cross Section
(SNI 2847 : 2019)

2.10 CONCRETE COMPRESSIVE STRENGTH REQUIREMENTS

SNI-2847-2019 article 19.2 specifies the limitation of concrete compressive strength taken in planning. The minimum required compressive strength value is 17 MPa. But for concrete on special moment bearing frame systems and special structural walls, the compressive strength of concrete is at least 21 MPa. (Antonius, 2021 : 14)

Table 2.3 Value Limitations *fc'*

Kegunaan	Jenis Beton	Nilai *fc'* Minimum (MPa)	Nilai *fc'* Maksimum (MPa)
Umum	Berat Normal, dan Berat Ringan	17	Tidak ada batasan

Sistem Rangka Pemikul Momen Khusus dan Dinding Struktural Khusus	Berat Normal		Tidak ada batasan
	Berat Ringan		35[1]
[1]Batasan diizinkan untuk dilewati bila bukti hasil eksperimental dari elemen struktur yang terbuat dari beton ringan menunjukan kekuatan dan keteguhan *(toughness)* yang sama atau melebihi dari elemen yang dibuat dengan menggunakan beton normal dengan kekuatan yang sama.			

Source*:* Table 19.2.1.1. *SNI 2847 : 2019*

2.11 CONCRETE BLANKET THICKNESS REQUIREMENTS

According to Antonius (2021: 14) Concrete blankets serve to protect reinforcement against fire, weather, chemical attacks such as corrosion or other effects and are measured from the outermost surface of the reinforcement. In addition, concrete blankets are also useful for developing attachments between reinforcing steel and concrete.

Based on SNI 2847:2019 R20.6.1.1 Concrete blankets which are reinforcement protection against weather or other effects are measured from the outermost surface of the reinforcement, in accordance with the applicable concrete blanket requirements. With concrete blankets for the class of structural components measured from the outermost side of the reinforcement, tie and spiral if the transverse reinforcement encloses the main reinforcement; from the outermost layer of the reinforcement if there is more than one layer of reinforcement used without Sengkang or ikat reinforcement; from the end-binding metal or post-attraction tendon sleeve; or from the outermost part of the head on the headed reinforcement rod.

Table 2.4 Thickness of Concrete Blankets for Non-prestressed Concrete Structure Components Cast on the Spot

<table>
<tr><th>Paparan</th><th>Komponen Struktur</th><th>Tulangan</th><th>Ketebalan Selimut (mm)</th></tr>
<tr><td>Dicor dan secara permanen kontak dengan tanah</td><td>Semua</td><td>Semua</td><td>75</td></tr>
<tr><td rowspan="2">Terpapar cuaca atau kontak dengan tanah</td><td rowspan="2">Semua</td><td>Batang D19 hingga D57</td><td>50</td></tr>
<tr><td>Batang D16, Kawat Ø13 atau D13 dan yang lebih kecil</td><td>40</td></tr>
<tr><td rowspan="3">Tidak terpapar cuaca atau kontak dengan tanah</td><td rowspan="2">Pelat, Pelat Berusuk dan Dinding</td><td>Batang D43 dan D57</td><td>40</td></tr>
<tr><td>Batang D36 dan yang lebih kecil</td><td>20</td></tr>
<tr><td>Balok, Kolom, Pedestal dan Batang tarik</td><td>Tulangan utama, Sengkang, Sengkang ikat, Spiral dan Sengkang Pengekang</td><td>40</td></tr>
</table>

Source*:* Table 20.6.1.3.1 *SNI 2847 : 2019*

Table 2.5 Thickness of Concrete Blankets for Components of Prestressed Concrete Structures Cast on the Spot

Paparan	**Komponen Struktur**	**Tulangan**	**Ketebalan Selimut (mm)**
Dicor dan secara permanen kontak dengan tanah	Semua	Semua	75
Terpapar cuaca atau kontak dengan tanah	Pelat, Pelat Berusuk dan Dinding	Semua	25
	Lainnya	Semua	40
Tidak terpapar cuaca atau kontak dengan tanah	Pelat, Pelat Berusuk dan Dinding	Semua	20
		Tulangan Utama	40
	Balok, Kolom, Pedestal dan Batang tarik	Tulangan utama, Sengkang, Sengkang ikat, Spiral dan Sengkang Pengekang	25

Source*:* Table 20.6.1.3.2 *SNI 2847 : 2019*

2.12 STRUCTURAL LOADING

Antonius (2021: 15) Suggests that the analysis of reinforced concrete structures is carried out after taking into account dead loads and live loads, wind loads, earthquake loads and so on that work on the structure. A dead load is a load that is always acting on the structure, working throughout time like its own weight. Speciation pairs on the floor, stucco, hanging loads such as ceilings are categorized as dead loads. A live load is defined as a load whose work is not forever, only once a certain time albeit with a rather high frequency. Included in this live load is for example the load of the vehicle. In addition to the two types of loads above, other loads that must also be taken into account are wind loads and earthquake loads. The last two loads must be taken into account even if the arrival of strong winds or earthquakes cannot be predicted when they come. (Antonius, 2021 : 16)

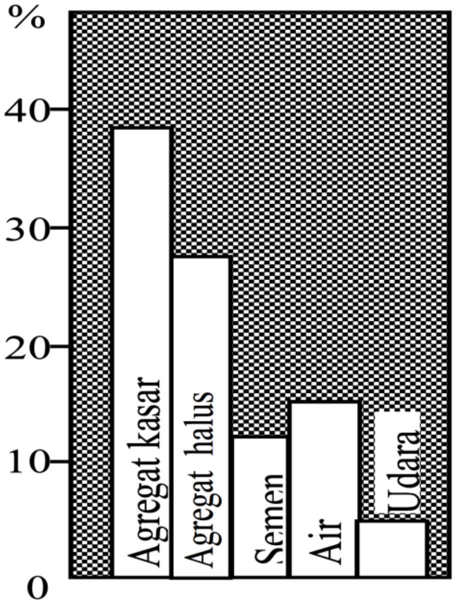
Table 2.6 Minimum Load to be taken into Account (SNI-1727-2020)

Penggunaan	Beban merata (kN/m^2)	Beban terpusat (kN)
Apartemen (lihat rumah tinggal)		
Sistem lantai akses		
• Ruang kantor	2,4	8,9
• Ruang komputer	4,79	8,9
Gudang persenjataan dan ruang latihan	7,18	
Balkon dan dek	1,5 kali beban hidup untuk daerah yang dilayani, namun tidak melebihi 4,79	
Ruang mesin elevator (pada daerah 50 mmx50mm)		1,33
Jalur penyelamatan terhadap kebakaran	4,79	
hunian	1,92	
Garasi/parkir mobil penumpang	1,92	
Helipad	2,87 (tidak boleh direduksi)	
Rumah sakit		
• Ruang operasi, laboratorium	2,87	4,45
• Ruang pasien	1,92	4,45
Koridor di atas lantai pertama	3,83	4,45
Pabrik		
• Ringan	6,0	8,90
• Berat	11,97	13,40
Gedung perkantoran		
• Ruang arsip dan komputer harus dirancang untuk beban yang lebih berat berdasarkan perkiraan hunian	4,79	8,90
• Lobi dan koridor lantai pertama	2,40	8,90
• Kantor	3,83	8,90
• Koridor di atas lantai pertama		
Rumah tinggal		
Hunian (satu keluarga dan dua keluarga)		
• Loteng yang tidak dapat didiami tanpa gudang	0,48	
• Loteng yang tidak dapat didiami dengan	0,96	
gudang	1,44	
• Loteng yang dapat didiami dan ruang tidur	1,92	
• Semua ruang kecuali tangga dan balkom		
Semua hunian rumah tinggal lainnya	1,92	
Ruang pribadi dan koridor yang melayani mereka	4,79	
Ruang publik dan koridor yang melayani mereka		
Atap yang digunakan untuk taman atap	4,79	
Sekolah		
• Ruang kelas	1,92	4,5
• Koridor di atas lantai pertama	3,83	4,5
• Koridor lantai pertama	4,79	4,5

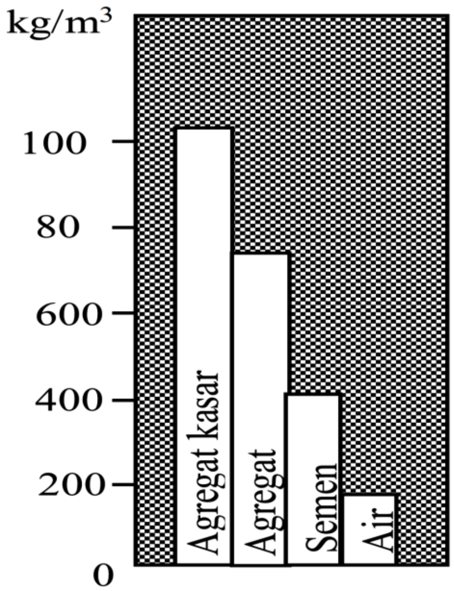
Source: (SNI 1727 : 2020)

2.13 CONCRETE MATERIAL

Concrete is a composite material consisting of cement, water and aggregate. The concrete hardens due to a chemical reaction that occurs between Portland cement and water. Portland cement consists of a large amount of calcium silicate. These silicas react with water to form calcium silica hydroxide which has a role in the strength of concrete, and calcium hydroxide which forms alkaline concrete. Portland cement also consists of tricalcium aluminate (C3A) which plays a role in forming alkaline concrete which also results in a chemical reaction to chloride ions that are occurring. In generals in concrete up to a compressive strength of about 50 MPa, coarse aggregates occupy the largest percentage in concrete fractions, followed by fine aggregates, water and cement. For examples Figure 2.6 shows the composition of the concrete mixture used for concrete with a compressive strength of 35 MPa. (Antonius, 2021 : 17)



a) Proportion of Concrete Mixture in Volume Mechanical Behavior of Concrete



b) Proportion of Concrete Mixture in Weight

Figure 2.6 The composition of the concrete mixture for *fc'* = 35 MPa (Collins & Mitchell, 1991)

2.14 CONCRETE MECHANICAL BEHAVIOR

According to Antonius (2021: 17) The basic material of concrete, namely cement paste and aggregate, is a material that has linear and brittle stress-strain properties in resisting pressure. Brittle materials tend to experience tensile cracks that are perpendicular to the direction of maximum tensile strain.

When withstanding uniaxial compressive loads, concrete is usually subjected to cracks that are parallel to the direction of the maximum compressive stress. But basically, when the concrete cylinder is tested with uniaxial compressive load, there are three types of collapse that occur, namely shear collapse (Figure 2.7a), splitting collapse (Figure 2.7b) and a combination of shear collapse and separation (Figure 2.7c).

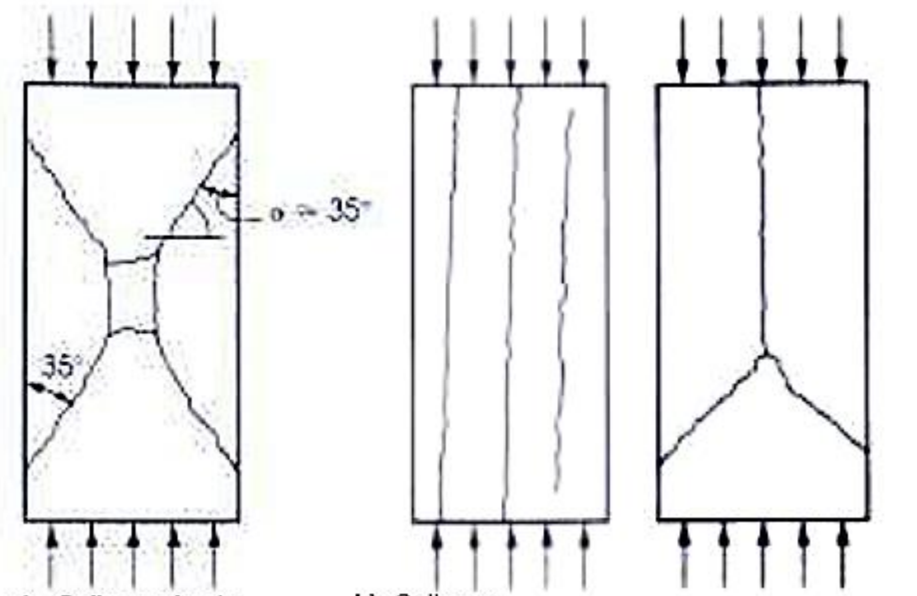


Figure 2.7 Concrete Material Collapse Pattern

2.14.1 Concrete Response to Uniaxial Loads

According to Antonius (2021: 18) The stress-strain relationship of concrete is normalized when subjected to compressive uniaxial loads monotonically seen in Figure 2.8 as described by Lowes (1999). In the loading process from the beginning until it reaches the stage $30\%\ fc'$, as the strain increases, the stress-strain behavior of concrete is still basically linear (zone A). At the stage of $30 - 50\% fc'$ that is, in zone B, cracks in the concrete surface begin to expand, and the rigidity of the concrete decreases. At this time there begins to be a deviation in the stress-strain relationship of the linear state. By the time the voltage reaches $50 - 75\% fc'$, the cracks of attachment propagate to the mortar so that a continuous cracking pattern is formed. Under these conditions, the stress-strain relationship of concrete further deviates from linear conditions and the rigidity of concrete is significantly reduced (zone C). After exceeding $75\% fc'$, concrete is getting more and more unstable, where cracks have reached in the transitional areas of mortal and aggregate, so that the attachment of materials between concrete constituents has been drastically reduced (zone D). Upon reaching peak stress, the concrete stress begins to decrease as the strain increases until the concrete disintegrates (zone E). It can also be seen in Figure 2.8 that if the concrete material is given a repeated load (reversal loading), then the surface collapse will be equal to the maximum loading process applied (Lowes, 1999).

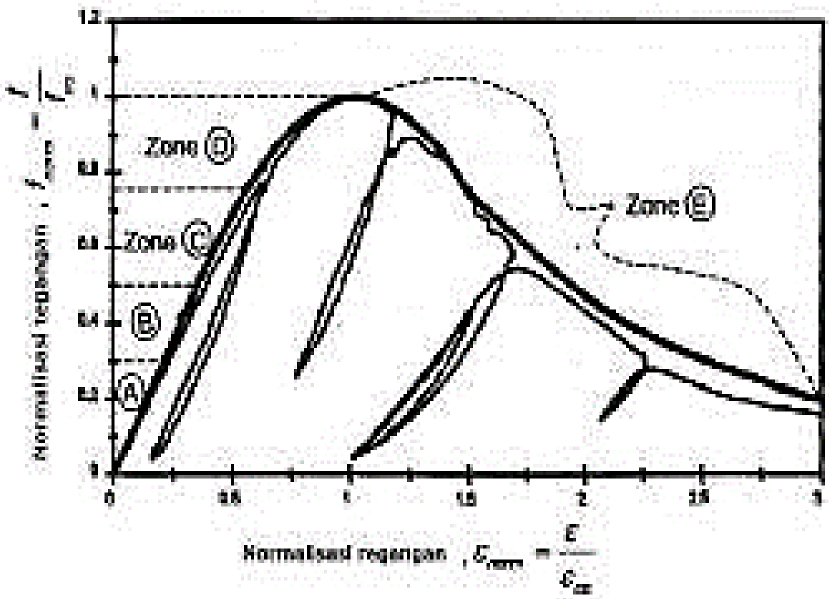


Figure 2.8 Concrete Response Curve to Uniaxial Compressive Load

Hognestad (1955) lowered the stress-strain relationship of concrete:

$$\sigma_c = f'_c \left[2\left(\frac{\varepsilon_c}{\varepsilon'_c}\right) - \left(\frac{\varepsilon_c}{\varepsilon'_c}\right)^2 \right]$$

Based on the equation, fc' and $\varepsilon c'$ each of them is the tension and peak strain of concrete. Value $\varepsilon c'$ varies between 0,0015-0,003. For normal weight concrete, $\varepsilon c'$ usually taken 0,002. In addition to the above strain there is also ultimate strain, εu, which is the maximum strain that can be utilized for analysis and bending design and cross-sectional axial pressure (Figure 2.9). SNI 2847-2019 article 22.2.2.1 assumes the value of εu is 0,003. (Antonius, 2021 : 19)

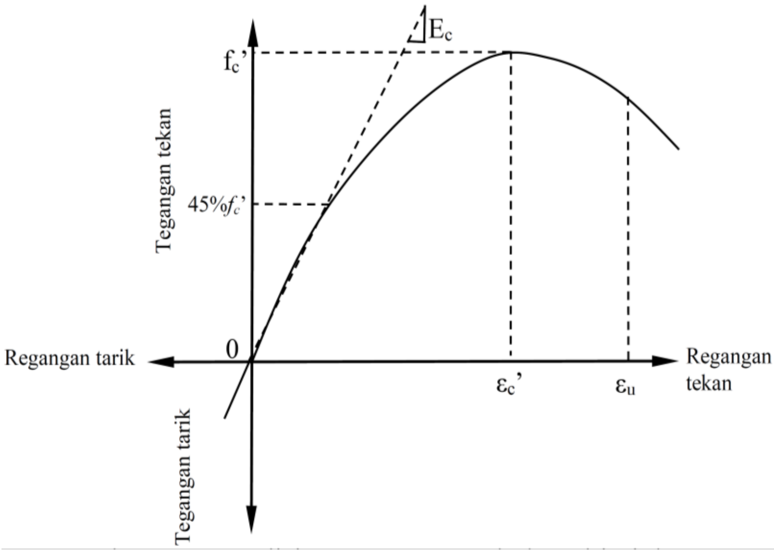


Figure 2.9 Peak Strain and Concrete Ultimate Conditions

1. **Tensile Strength of Concrete**

   Antonius (2021) suggests Figure 2.10 is a tensile stress-strain curve of concrete that is normalized against monotonic loads. The tensile strength of concrete is much less than its compressive strength, that is, ft'=10%fc'. The behavior of concrete at the time of being subjected to uniaxial tensile loads is different from its behavior in withstanding compressive uniaxial loads. The tensile stress-strain relationship of concrete is generally linear until a crack occurs which is usually directly followed by a concrete collapse. The relationship of direct tensile strength, ft, to concrete compressive strength, fc' is as follows:

$$ft = 0{,}33\sqrt{fc'}$$

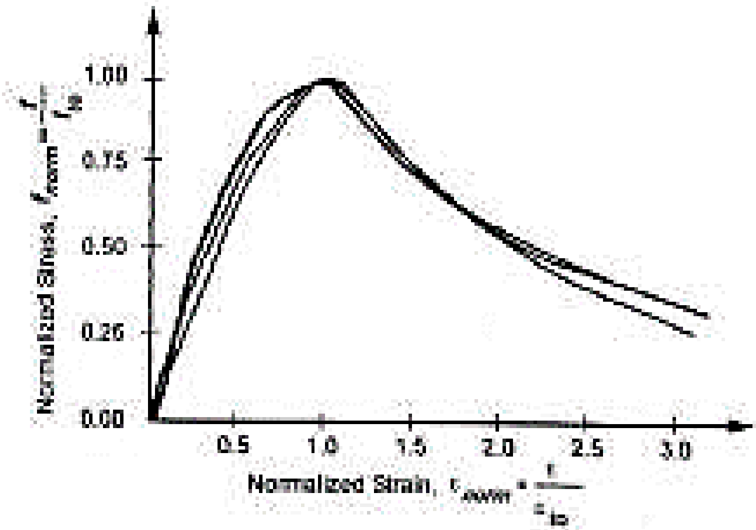


Figure 2.10 Strong Relationship of Concrete Tensile to Axial Deformation Due to Monotonic Load (Lowes,1999).

Neville (1997) describes the relationship between compressive strength to the tensile strength of concrete of a non-linear nature shown in Figure 2.11. (Antonius, 2021 : 20)

Based on Antonius (2021) In addition to the two mechanical magnitudes above, the other magnitude is the bending strength of concrete expressed through the bending modulus or bending collapse modulus. The relationship of the modulus of bending collapse, fr, to the compressive strength of concrete, fc', there are 2 types, namely:

- For deflection calculation

$$\boldsymbol{fr = 0{,}7fc}$$

- For the calculation of the shear strength of the prestressed beam

$$\boldsymbol{fr = 0{,}5fc}$$

The tensile strength of concrete can be obtained through direct tensile testing (Figure 2.12a), indirect tensile testing or split test (Figure 2.12b), bending test

(Figure 2.12c) and "double punch" test (Figure 2.12d). (Antonius, 2021 : 21)

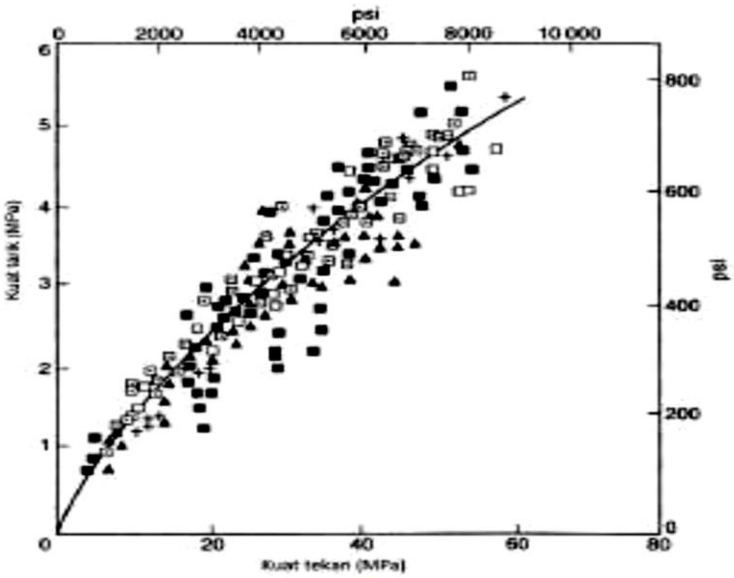
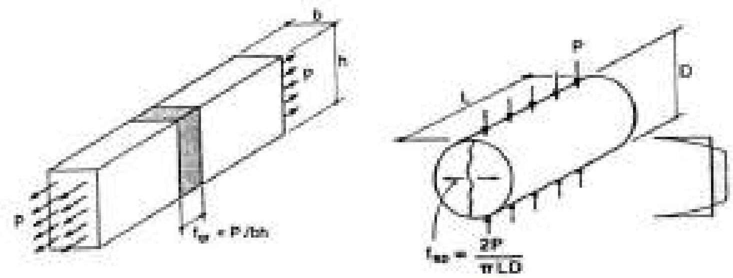
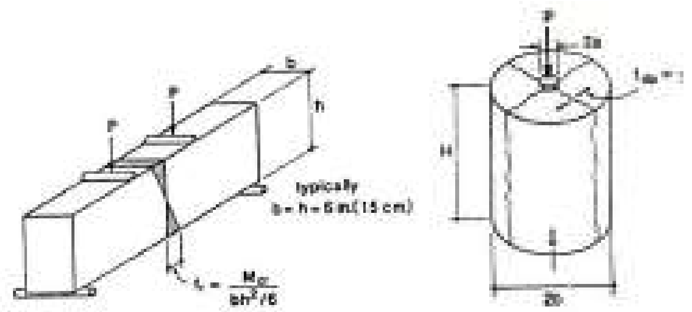


Figure 2.11 Relationship Between Compressive Stress and Tensile Stress of Concrete (Neville, 1997)



a) Direct Tensile Test b) Split Tensile Test



b) Bending Tensile Test d) “Double Punch” Test

Figure 2.12 Concrete Tensile Testing Methods (Antonius, 2021)

2. Modulus of Elasticity of Concrete

Based on SNI 287:2019 R19.2.2.1 Studies related to the formulation of a modulus of elasticity of concrete are summarized in Pauw (1960), where Ec is defined as the slope of a line drawn from zero voltage to a compressive stress of 0,45*fc'*. The modulus of elasticity for concrete is sensitive to the modulus of elasticity of the aggregate and the proportions of the concrete mixture. The measured modulus of elasticity values the range from 80 to 120 percent of the calculated value. ASTM C469M provides a test method for determining the modulus of elasticity for concrete subjected to compression. The modulus of elasticity of concrete, Ec, is allowed to be calculated on the basis of a) or b):

a) For the wc value in between 1400 dan 2560 kg/m^3

$$\boldsymbol{Ec} = (\boldsymbol{Wc})^{\mathbf{1,5}}.\mathbf{0,043}\boldsymbol{fc'}(\boldsymbol{MPa})$$

b) For normal concrete

$$\boldsymbol{Ec} = \mathbf{4700}\sqrt{\boldsymbol{fc'}}(\boldsymbol{Mpa})$$

According to Antonius (2021) This modulus of elasticity is defined as the slope of a straight line drawn from a zero-voltage state to a compressive stress state 0,45fc' on the stress-strain curve of concrete. For stress-strain calculations using the previous equation, the modulus used is the initial tangent modulus, that is,:

$$\boldsymbol{E_{ct}} = \frac{\mathbf{2}.\boldsymbol{f_c}}{\boldsymbol{\varepsilon'}}$$

3. Concrete Crack Modulus

Based on SNI 2847:2019 Fr concrete crack modulus can be calculated using:

$$\boldsymbol{f_r} = 0{,}62\lambda\sqrt{fc'}$$

2.14.2 Concrete Response to Biaxial Loads

The response of concrete to biaxial loading is often found in the case of wall elements (walls), panels, namely mainly precast structures (precast) and high beams (deep beam). The results of the research of Imran et al. (1999) stated that the strength of concrete to the biaxial stress depends on the ratio $a = \sigma 2/\sigma 1$. The response of concrete to biaxial loads and their comparative response to uniaxial loads are shown in Figure 2.13. Due to the biaxial stress, in biaxial compression, the strength of concrete can increase $\pm 20\%$, in the biaxial compressive area: there is an increase in strength, rigidity and ductility, in the area of tensile - compressive: The compressive force decreases as the tensile increases, as is the case with the ductility, and in the area of Tensile - tensile: there is almost no interaction between the two directions. (Antonius, 2021 : 23)

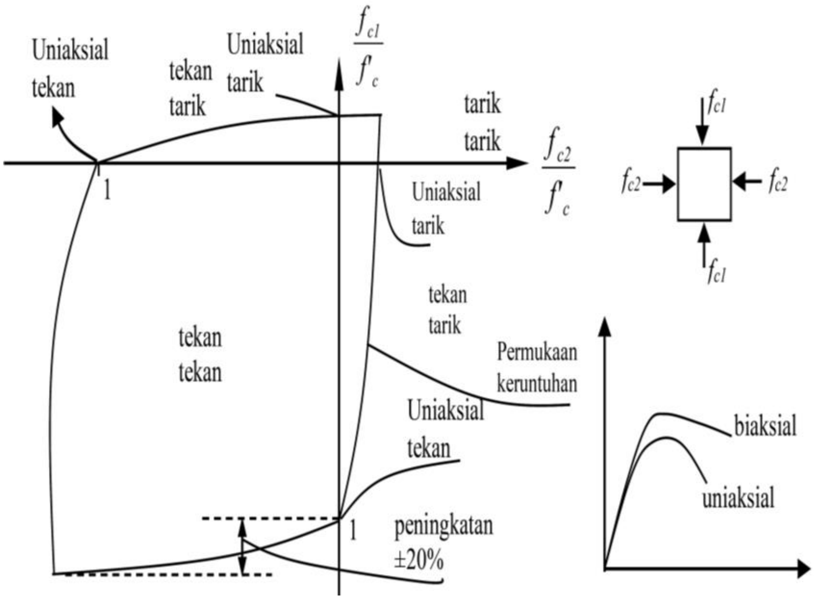


Figure 2.13 Concrete Response to Biaxial Loads

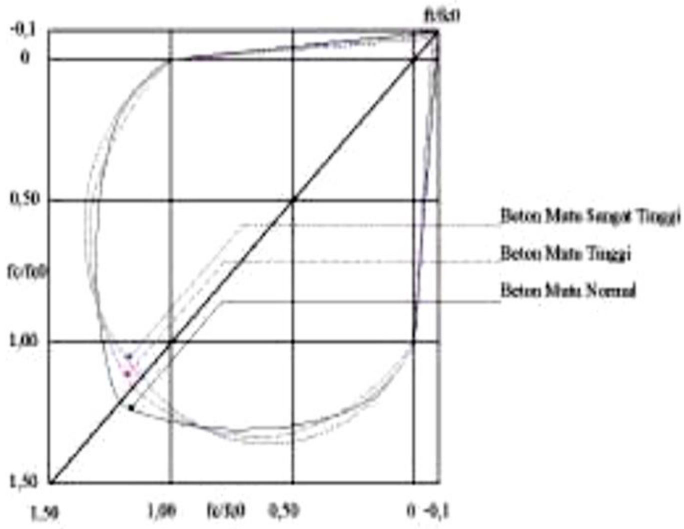
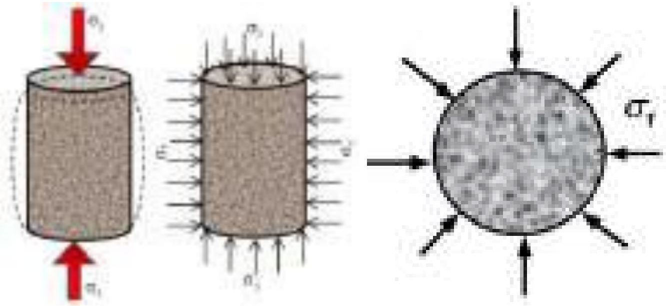


Figure 2.14 Concrete Collapse Surface Against Biaxial Load on Normal Quality to High Quality Concrete

2.14.3 Concrete Response to Triaxial Loads

The behavior of concrete to triaxial loads is the basis for studying the behavior of confined concrete. Figure 2.15 describes concrete that receives compressive axial loads and lateral development occurs in the concrete core due to the effect of the Poisson ratio and the dilatation properties of the material. Such lateral development can be inhibited by providing a lateral stress effect on the concrete core (σ_3) so that the concrete is in a constrained condition. Under such conditions, concrete will have a higher compressive strength and behave dactyl. To curb the core of a concrete column, a spiral or a round hoop can be used, as well as a square hoop that in its restraint performs an arc action to apply lateral stress. (Antonius, 2021 : 24)



a) Uniaxial load and restraint on concrete cylinders

b) Lateral voltage at the cross section of the core

c) Restraint bow action

Figure 2.15 Restraint Mechanism in Concrete

Imran & Pantazopoulou (1996) illustrates the mechanism of concrete response to triaxial loads as shown in Figure 2.17. Based on this, before the application of lateral stress $(\sigma 1 = \sigma 2 = \sigma lat. = 0)$, then the concrete is in a condition of uniaxial loading (one-way load i.e. vertical). The presence of lateral stress imposed on the concrete ($\sigma lat.$=moderate), then the concrete is in a confined state, and the axial stress of concrete $(\sigma 3)$ began to increase. As the lateral voltage increases higher and higher $(\sigma 1 = \sigma 2 = \sigma lat. = high)$, the strength of concrete in the axial direction (σ3) will also increase significantly. The increase in lateral stress applications above causes the ductility of concrete materials to also increase, which is characterized by the increasingly gentleness of the concrete response curve after the peak response. (Antonius, 2021 : 24)

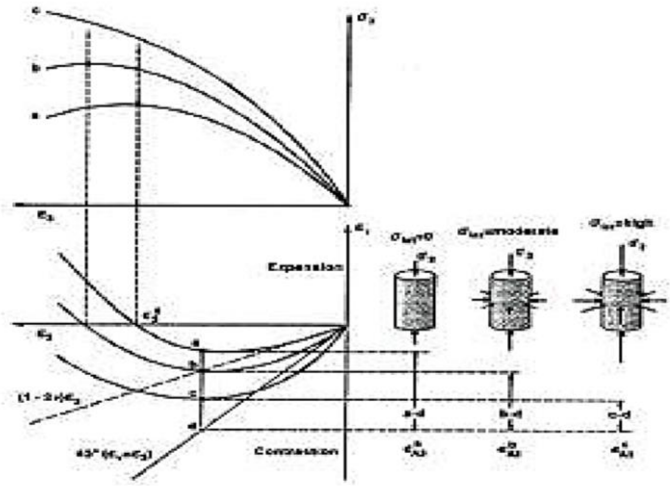


Figure 2.16 Concrete Response to Triaxial Loads (Imran & Pantazopoulou, 1996). (Antonius, 2021)

The strength of concrete with a combination of stresses can also be expressed by using the Mohr Circle (Figure 2.17). In the picture is plotted uniaxial loaded concrete ($\sigma 3 = 0$) and other circles where there is a lateral voltage ($\sigma 3 \neq 0$). With the application of lateral stress, it will naturally increase the axial voltage ($f1$), and there is also another influence, namely the occurrence of shear collapse (v), (ordinate direction). The magnitude of the increase in compressive stress due to the restraint effect caused by the lateral voltage can be lowered based on the Mohr-Coulomb melt criterion. (Antonius, 2021 : 25)

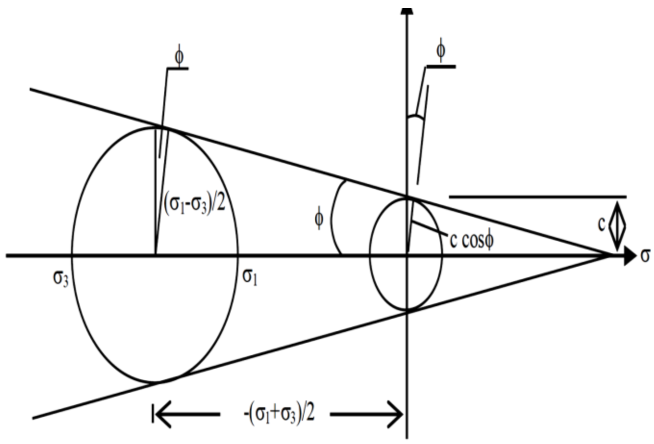


Figure 2.17 Relationship Between Main Shear Stresses Mohr-Coulomb Criteria

The Mohr-Coulomb criterion is expressed in the equation:

$$|\boldsymbol{\tau}| = \boldsymbol{c} - \boldsymbol{\sigma}\ \boldsymbol{tan}\emptyset$$

Based on Figure 2.18, the above equation can be changed to (Chen, 1982):

$$\boldsymbol{\sigma_1}\ \frac{\mathbf{1} + \boldsymbol{Sin}\emptyset}{\mathbf{2}_{\boldsymbol{c}}\boldsymbol{Cos}\emptyset} - \ \boldsymbol{\sigma_3}\ \frac{\mathbf{1} - \boldsymbol{Sin}\emptyset}{\mathbf{2}_{\boldsymbol{c}}\boldsymbol{Cos}\emptyset} = \mathbf{1}$$

For constraint (confinement) to occur:

$$\sigma_1 \ \geq \ \sigma_2 \ \geq \ \sigma_3 \qquad \text{or} \qquad \frac{\boldsymbol{\sigma_1}}{\boldsymbol{f'_t}} - \frac{\boldsymbol{\sigma_3}}{\boldsymbol{f'_c}} = \mathbf{1}$$

Where,

$$\boldsymbol{f'_c} = \frac{\mathbf{2}\ \boldsymbol{c}\ \boldsymbol{Cos}\ \emptyset}{\mathbf{1} - \boldsymbol{Sin}\ \emptyset} \qquad \text{and} \qquad \boldsymbol{f'_t} = \frac{\mathbf{2}\ \boldsymbol{c}\ \boldsymbol{Cos}\ \emptyset}{\mathbf{1} - \boldsymbol{Sin}\ \emptyset}$$

If,

$$\boldsymbol{m} = \frac{\mathbf{1} + \boldsymbol{Sin}\ \emptyset}{\mathbf{1} - \boldsymbol{Sin}\ \emptyset} = \frac{\boldsymbol{f'_c}}{\boldsymbol{f'_t}}$$

Then the above equation can be changed to:

$$\boldsymbol{m}\ \boldsymbol{\sigma_1} - \ \boldsymbol{\sigma_3} \ = \ \boldsymbol{f_c}'$$

Equations can be developed into:

$$\boldsymbol{K} = \frac{\boldsymbol{f_{cc}}'}{\boldsymbol{f_c}'} = \mathbf{1} + \boldsymbol{m}\ \frac{\boldsymbol{f_2}}{\boldsymbol{f_c}'}$$

Antonius (2021 : 26) suggests where fc' is synonymous with the compressive stress of constrained concrete ($= -\boldsymbol{\sigma_3}$), $\boldsymbol{f_2}$ is the restraint voltage ($= -\boldsymbol{\sigma_3}$), and fc' is the compressive strength of concrete against uniaxial loads. The coefficient m in the equation above is obtained from the results of experimental tests.

The results of studies that have been carried out by Richart et al. (1928) reveal that the value of the m of the above equation. So that with the application of lateral stress, there is a significant increase in axial voltage expressed in the following equation($\boldsymbol{\sigma_3}$) :

$$\boldsymbol{\sigma_3} = \ \boldsymbol{f'_c} + \ \boldsymbol{\sigma Lateral}$$

The equation is used as the basic philosophy for the determination of lateral reinforcement as a restraint (confined) in concrete regulations in various countries such as the Indonesian Concrete Regulation (SNI), the American Concrete Regulation (ACI) and the Canadian Concrete Regulation (CSA). (Antonius, 2021 : 26)

The results of research by Xie et al. (1994), Ansari & Li (1998), Imran et al. (1999) revealed that as high-quality concrete is restrained, the Mohr-Coulomb criterion is less accurate when applied with high lateral stress applications. It is reported that for curbed concrete with higher quality, the melting surface pattern of the Ottosen criterion is more suitable, both for conditions of small lateral loading and large lateral loading, since the equation of its melting criteria is derived for various loading conditions and is not linear to the meridian plane (Figure 2.18). (Antonius, 2021 : 26)

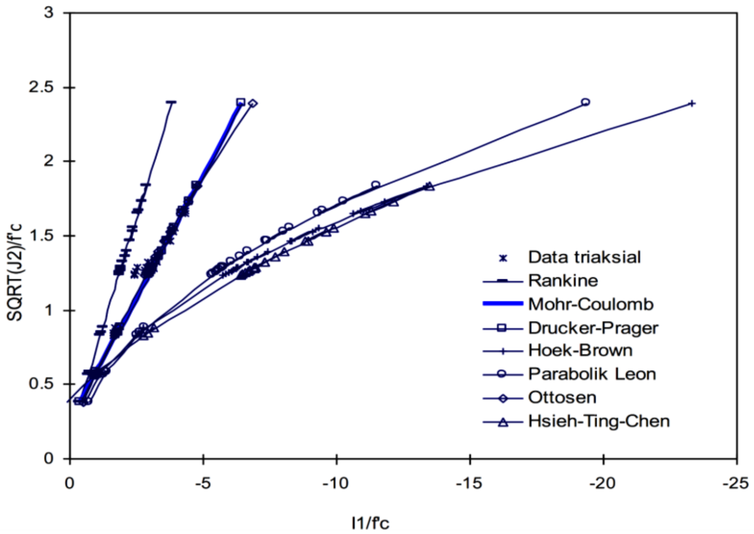


Figure 2.18 Collapse of High-Quality Concrete Against Triaxial Load (Suharwanto, 1997). (Antonius, 2021)

2.15 HIGH QUALITY CONCRETE

2.15.1 Definition and Characteristics

According to Antonius (2021), concrete technology has developed rapidly in the last four decades. The need for quality, high-use materials, having a long service life and being resistant to weather changes has become the main goal for the development of concrete technology in this modern era. Basically, to increase the compressive strength of concrete is divided into three categories, namely the increase in the strength of the cement matrix, the increase in the strength of the aggregate and the increase in the adhesion between the cement matrix and the aggregate. The increase in the strength of the cement matrix depends on the hydration speed and porosity of the matrix. Porosity increases if the ratio of water to cement (w/c) also increases. Therefore, the reduction of the w/c ratio will result in concrete with a higher compressive strength. High Quality Concrete can be produced by reducing the level of porosity in the concrete material (Figure 2.19). The pores are closed by fine grains that have a smaller and finer size than cement and are pozolan such as Fly Ash, Silica Fume or Slag, so that the bond between concrete constituent materials becomes denser and more compact.

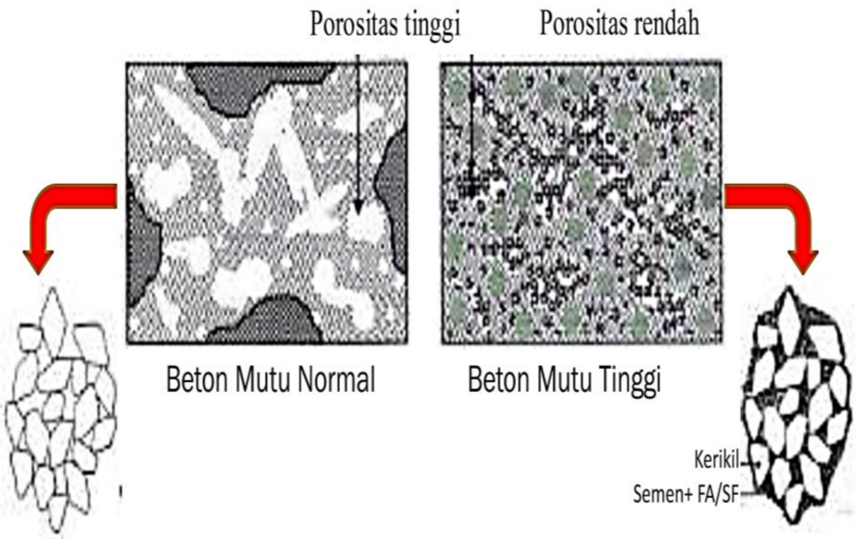


Figure 2.19 Difference Between Porosity Rate of BMN and BMT **(Antonius, 2021)**

Antonius (2021) stated that the compactness of materials made of BMT makes the material not easily penetrated by materials that can damage the bonds between concrete particles such as chloride ions, NaCl, so that BMT is not easily weathered and very durability. The characteristics of BMT are also superior to BMN, such as higher cracking and rigidity kink, shrink-ability, frame and lower permeability. These properties make BMT very suitable to be applied to prestressed concrete structures as well as structures that are dominant in withstanding axial loads such as column structures. Some of the advantages obtained by the use of BMT in building construction are the smaller dimensions needed in the cross section of structural elements, the use of beams with longer spans and offshore building construction because BMT has good waterproof properties. The superior properties of BMT result in the material having excellent prospects for use in the future.

High-quality concrete materials have different characteristics compared to normal quality concrete. Some of the distinctive properties that high-quality concrete has are high strength, high starting strength, high modulus of elasticity, high resistance to abrasion, durable and still survives for a long time under various conditions, low permeability, more resistant to chemical attacks, low shrinkage and so on. Because of these superior properties, high quality concrete is often also referred to as high performance concrete. The constituent materials of high-quality concrete generally have special characteristics and options and are designed in such a way as to achieve superior strength. In general, the ratio of water to cement in high-quality concrete is in the range of values from 0.20 to 0.45. To anticipate the low water content used, a superplasticizer material is added so that the workability of fresh concrete can be maintained properly. (Antonius, 2021 : 35)

2.15.2 High Quality Concrete Mix Design

According to Antonius (2021) there have been many procedures for the manufacture of high-quality concrete such as mixed plans based on ACI and fib. Mehta (1991) introduced the planning method of high-quality concrete mixtures by making modifications to the ACI method which is simpler but more accurate. The steps based on the ACI method are described below.

Step 1: Selection of Compressive Strength of Concrete

The compressive strength of the designed concrete is 60 to 120 MPa, and it is divided into 5 groups namely A (65 MPa), B (75 MPa), C (90 MPa), D (105 MPa) and E (120 MPa). The value of such compressive strength is the average compressive strength of concrete at the age of 28 days. Calculations of average compressive strength on various grades of concrete are listed in Table 2.7.

Table 2.7 Concrete Compressive Strength Design and Water Content Estimation

Group Compressive Strength	Compressive Strength Average (MPa)	Water Content Maximum (Kg/m^3)
A	65	160
B	75	150
C	90	140
D	105	130
E	120	120

(Antonius, 2021)

Table 2.8 Calculation of Average Compressive Strength

Target Compressive Strength f'c (Psi)	Compressive Strength Requirements Average f'cr (Psi)
<3000	f'c + 1000
3000 ≤ f'c ≤ 5000	f'c + 1200
> 5000	f'c + 1400

(Antonius, 2021)

Step 2: Estimation of Water Mixture

The estimation of the water content used is based on the compressive strength of the designed concrete, and is shown in table 2.9. The estimate is based on experience that the value of fresh concrete slumps is quite high (workable) if using Superplasticizer additives, and the maximum aggregate size is 12-19 mm.

Step 3: Estimated Amount of Cement

The total volume of cement paste is estimated at 0.35 m3 and trapped air is assumed to be 2%, so the calculation of the total volume of cement paste in each concrete quality group is presented in table 2.8. furthermore, in the table there are three choices of cement paste mixtures, namely:

a) Using only Portland cement.
b) Using Portland cement and Fly Ash (FA) or slag (BFS) with a volume ratio of 75:25.
c) Using Portland cement + FA or slag+slica fume (SF) with a volume ratio of 75:15:10.

Table 2.9 Components of The Mixture Inside the Cement Paste In Volume 0,35 M^3

Kelompok kuat tekan	Air	Udara	Material semen total	Pilihan 1 (Hanya semen)	Pilihan 2 (Semen+FA/ Slag)	Pilihan 3 (Semen+FA/Slag+SF)
A	0,16	0,02	0,17	0,17	0,1275+0,0425	0,1275+0,0255+0,0170
B	0,15	0,02	0,18	0,18	0,1350+0,0450	0,1350+0,0270+0,0180
C	0,14	0,02	0,19	0,19	0,1425+0,0475	0,1425+0,0285+0,0190
D	0,13	0,02	0,20	*	0,1500+0,0500	0,1500+0,0300+0,0200
E	0,12	0,02	0,21	*	0,1575+0,0525	0,1575+0,0315+0,0210

(Antonius, 2021)

Step 4: Estimated aggregate content

The remaining volume of aggregate contained in the concrete mixture is 0.65 m3. The assumption of volume comparison between fine aggregates to coarse aggregates is taken as in Table 2.10.

Step 5: Calculation

Calculate cement and aggregate requirements based on specific gravity data from each material. The calculation results obtained must be corrected again if using a superplasticizer. (Antonius, 2021)

Table 2.10 Comparison of The Volume of Fine Aggregate to Coarse Aggregate at Various Grades of Concrete

Compressive Strength Group	Comparison
A	2 : 3
B	1,95:3.05
C	1,90:3,10
D	1,85:3,15
E	1,80:3,20

(Antonius, 2021)

2.15.3 High Quality Concrete Mix Design Example

Antonius (2021), Mix plan for concrete compressive strength of 80 MPa using Fly Ash added material. The calculated concrete compressive strength plan (fcr) is rounded upwards to 90 MPa. In table 2.6 the compressive strength of this concrete includes grade C.

The need for water conveying = 0,13 m^3

Air content = 0,02 m3

Volume pasta = 0,35 m3

The volume of cement and fly ash = 0,20 m3

Aggregate volume = 0,65 m3

The ratio of cement and fly ash (FA) = 75:25

Estimated aggregate content

The fly ash used is class F and is taken 15% of the weight of the cement, then the amount of cement used is 85%:

$$= \frac{0,85\ x\ PC}{BJ\ PC} + \frac{0,15\ x\ PC}{BJ\ FA} = 0,20\ m^3$$

$$= \frac{0,9\ x\ PC}{3110} + \frac{0,1\ x\ PC}{2120} = 0,18\ m^3$$

Obtained PC (cement) = 581,28 kg

PC Needs = 0,85 x 581,28 = 494,09 kg

The need for fly ash = 0,15 x 581,28 = 87,19 kg

Calculation of the weight of the aggregate mixture

The ratio of sand to gravel is 1,85: 3,15

$$= \frac{1,85\ x\ A}{BJ\ Pasir} + \frac{3,15\ x\ A}{BJ\ Kerikil} = 0,65\ m^3$$

$$= \frac{1,85\ x\ A}{2578} + \frac{3,15\ x\ A}{2702} = 0,65\ m^3$$

Retrieved A = 345, 12 kg

The need for sand = 1,85 x 345, 12 kg = 638,47 kg

Gravel requirements = 3,15 x 345,12 kg = 1087,12 kg

Superplasticizer (SP)

Taken SP of 1.5% of the weight of cement so SP = 1,5% x 581,28 = 8,72 kg

BJ SP = 1,19 so,

The required amount of SP in liters = 7,33 liter

The composition of the concrete mixture every 1 m^3:

1. Cement = 494,09 kg/m^3
2. Fly ash = 87,19 kg/m^3
3. Water = 130 lt/m^3
4. w/c = 0,26
5. Superplasticizer (SP) = 7,33 lt/m^3
6. Sand = 638,47 kg/m^3
7. Gravel = 1087,12 kg/m^3

2.15.4 High Quality Concrete Mechanical Quantity

In high-quality concrete, the stress-strain equation proposed by Thorendfeldt et al. has become the main reference in research and design purposes, namely:

$$\frac{f_c}{f'_c} = \frac{\varepsilon_c}{\varepsilon'_c}\frac{n}{n-1+\left(\frac{\varepsilon_c}{\varepsilon'_c}\right)^{nk}}$$

Where, $n = \left(1 + \frac{f'_c}{17}\right)$

$k = 1$ for $\frac{\varepsilon_c}{\varepsilon'_c} < 1$

$k = 0,67 + \frac{f'_c}{62}$ for $\frac{\varepsilon_c}{\varepsilon'_c} \geq 1$

Peak strain equation ε_{co}' proposed by Antonius et al (2000). Equation ε_{co}' based on regression of test result data, is:

$$\varepsilon'_c = 0,0004\,.(fc')^{0,45}$$

Eurocode-02 determine the tensile strength of concrete as follows:

- For $f'_c \leq 50\ MPa$ $\quad f'_t = 0,30\, f'_c{}^{2/3} MPa$
- For $f'_c > 50\ MPa$ $\quad f'_t = 2,12 ln\left(1 + \frac{f'_t}{10}\right)\ MPa$

But on high quality concrete, Carrasquillo et al. recommend bending strength as follows:

$$f_r = 0,94\,\sqrt{f_c}$$

NZS-3101-06 corrected the value of 0.94 with a value of 0.8, so that the bending strength of the concrete becomes:

$$f_r = 0,8\,\sqrt{f_c}$$

In high-quality concrete, the modulus of elasticity according to Eurocode is:

$$E_c = 22000\left(\frac{f'_c}{17}\right)^{0,3}$$

According to CSA dan NZS:

$$E_c = (3320\sqrt{f'_c} + 6900)\left(\frac{w_c}{2300}\right)^{1,5}$$

2.16 FRESH CONCRETE

Antonius (2021: 45) suggests that fresh concrete is a mixture of water, cement, aggregates and auxiliary materials if needed. After the completion of stirring, efforts such as transportation, casting, compaction and finishing, can all affect the concrete that has hardened. At these different levels of processing, it is very important that the materials of the concrete mixture remain evenly divided in the entire mortar and all are well compacted. If any of the above processing methods are not carried out satisfactorily, then the properties of the resulting concrete such as compressive strength and durability are not good.

The characteristics of fresh concrete that affect the full compaction of concrete are its viscosity, ease of movement (flow) and ease of compaction. In concrete technology such properties have usually been covered in terms of concrete workmanship properties. The ability of concrete to maintain its uniformity is influenced by its stability, which depends on its viscosity as well as adhesion. Because the methods used for the transportation, casting and compaction of a concrete mixture and also the shape of the concrete element to be cast vary from one job to another, the requirements regarding the nature of the workmanship and stability vary also. (Antonius, 2021)

2.16.1 Concrete Working Properties

According to Antonius (2021) Concrete that can be compacted easily is called workable concrete, or has good workability. The three main characteristics of the working properties of concrete are: its viscosity, ease of flow (movement) and ease of compaction. The viscosity or consistency of concrete is a measure to indicate the wet or liquid state of the concrete in question. Ease of movement or mobility states the ease or difficulty of the concrete mixture flowing into the reference or mold, as well as filling it to the brim. The ease of compaction indicates the ease or difficulty of a concrete mixture being compacted entirely, so that the air trapped in it can be expelled.

In this regard, the nature of the workmanship required for a concrete mixture depends not only on the characteristics and ratio of the mixed materials, but also on the way of transportation and compaction, the size, shape and roughness of the reference surface or mold and the number and distance between reinforcements. Another definition of the commonly used workmanship properties is the amount of useful internal work required for the full compaction of the concrete in question. The work required depends on the shape as well as the surface state of the mold reference. (Antonius, 2021 : 46)

2.16.2 Factors Affecting the Nature of Concrete Workmanship

1. Cement Water Factor

For certain cement, water and aggregate grades, the working properties of concrete are mainly influenced by the surface area of such aggregates. The nature of the work becomes worse whenever the surface area of the type of concrete mixture materials in question increases, because more cement paste is needed to coat the aggregate grains, so that thus for lubrication only a small amount of cement paste is left. Under the same conditions, the workmanship properties will increase if the maximum size of the aggregate increases in size, the grains of the aggregate round or the overall gradation becomes rough. However, the magnitude of the change in the nature of the workmanship depends on the ratio of the concrete mixture material and for the greased mixture, with the ratio of cement aggregates close to the value of 2, then the influence of the aggregate can be ignored. (Antonius, 2021 : 47)

2. Effect of Aggregate Proportions

Factors regarding the angled aggregate along with the modulus of the gradation and the average diameter of the equivalent equip us with a way to successively make considerations about the shape, size and gradation of the fully compacted aggregate. For certain mixed materials and cement water factors, it does not depend on the ratio of coarse aggregates to fine aggregates, then the concrete in question can be made maximally-economically by using coarse aggregate grades that produce concrete with the easiest working properties and with a certain cement grade. (Antonius, 2021 : 47)

The fraction that hits the volume of the aggregate is an important thing, besides its weight. Aggregates with a slippery surface arrangement are better working properties compared to aggregates that have a rough surface. The absorbency of the aggregate also affects the working properties of concrete whenever dry or partially dry aggregates are used. Under such circumstances the nature of the workmanship decreases to less good, the degree of decrease depends on the aggregate content as well as the absorbency. (Antonius, 2021 : 47)

3. Properties of Aggregates

The shape and texture of the aggregate also affects workability. The closer the particle approaches the spherical shape, the easier it is to work with. Sperical particles have a small area/ volume ratio so it takes a little mortar to coat the particles. Medium flattened and elongated shapes require a greater amount of cement and water. The porosity of the aggregate can also affect workability. If the aggregate is only able to absorb a small amount of water then the workability is low. (Antonius, 2021 : 48)

4. State of the Environment

Environmental factors that can affect the working properties of concrete are temperature, humidity and wind speed. For certain concrete, changes in the nature of the workmanship are influenced by the degree of hydration of the cement and the degree of evaporation of water. Therefore, the long term of time from the beginning of stirring to compaction as well as environmental influences affect the deterioration of the nature of the concrete work in question. Rising temperatures accelerate the amount of water used needed for hydration and loss processes due to evaporation and also reduced slump values (Figure

2.20). Similarly wind speed and humidity affect the nature of the workmanship as well as the degree of evaporation of water. It is worth remembering that in practice those factors depend on the state of the weather and cannot be controlled. (Antonius, 2021 : 48)

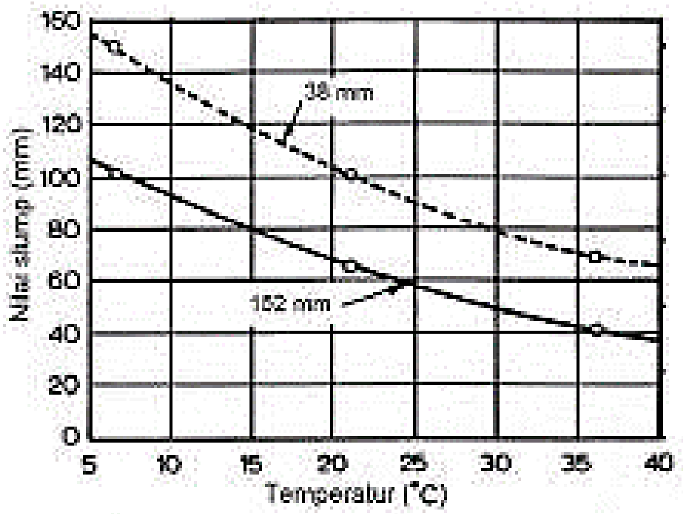


Figure 2.20 Effect of Temperature on Concrete Slump Value with Maximum Aggregate Size Difference (Neville, 1996). (Antonius, 2021)

5. Foundry Time

The time elapsed between the stirring and the final compaction of the concrete depends on the general state of the work, such as the distance between the concrete mixer and the foundry place, local regulations and management in general. The deterioration of the nature of the workmanship with respect to time, is a direct result of the loss of free water through evaporation, absorbency of the aggregate and the initial hydration of the cement. The degree of deterioration of the working properties is influenced by certain characteristics of the materials of the mixture, for example, hydration of the cement accompanied by the heat it causes, the moisture content of the original and the permeability of the aggregate, as well as the state of the environment. For concrete under certain environmental circumstances, the degree of deterioration of the nature of the workmanship is related to time, depending on the means of processing the concrete in question. Figure 2.22 illustrates the decline in the value of the slump as the foundry time increases. (Antonius, 2021 : 49)

Concrete that can be compacted easily is called workable concrete, or it has good workability. The three main characteristics of the working properties of concrete are: its viscosity, ease of flow (movement) and ease of compaction. The viscosity or consistency of concrete is a measure to indicate the wet or liquid state of the concrete in question. Ease of movement or mobility states the ease or difficulty of the concrete mixture flowing into the reference or mold, as well as filling it to the brim. The ease of compaction indicates the ease or difficulty of a concrete mixture being compacted entirely, so that the air trapped in it can be expelled. In this regard, the nature of the workmanship required for a concrete mixture depends not only on the characteristics and comparisons of mixed materials, but also on the way of transportation and compaction. (Antonius, 2021 : 50)

6. Effect of Treatment

In order for the hydration process for cement to take place satisfactorily, there are absolute conditions that must be met, namely treatment. For certain types of concrete, the speed as well as the amount of cement undergoing hydration and the physical state of the hydration product depend on the process of temperature-time changes. In general, the longer the concrete is soaked in water, the greater the compressive strength that can be achieved. It has also been generally recognized that concrete made using ordinary portland cement and treated according to applicable requirements, will reach maximum compressive strength at the age of 28 days. (Antonius, 2021 : 51)

2.17 STEEL REINFORCEMENT

Antonius (2021) stated that in SNI, reinforcement that can be used in reinforced concrete elements is limited to reinforcement or steel wire only. There are two types of steel reinforcement on the market, namely plain reinforcement and threaded reinforcement. Plain reinforcement usually has a melting stress of 240-280 MPa while threaded reinforcement generally has a melting stress between 320 and 420 MPa (Figure 2.21).

Figure 2.21 Types of Threaded Reinforcing Steel

Plain rebar that is commonly found in the market is $\phi 6, \phi 8, \phi 10, \phi 12, \phi 16$. as for threaded reinforcement, almost all the sizes in the table above are on the market. However, SNI 2847-2019 article 20.2.1.1 provides that the reinforcement used for the structure must be threaded reinforcement. Plain reinforcement is only allowed for spiral, prestressed steel and sliding stud reinforcement. Table 2.11 is the notation of writing threaded reinforcement along with its nominal diameter. (Antonius, 2021)

Table 2.11 Reinforcement and Its Size

Reinforcement	Nominal Diameter (mm)
D10	10
D13	23
D16	16
D19	19
D22	22
D25	25
D28	28
D32	32
D36	36

(Antonius, 2021)

2.17.1 Steel Strain Stress Behavior

According to Antonius (2021), the strain stress behavior of various types of steel is implicated on each other which shows that reinforcing steel has the same rigidity or has a fixed modulus value of elasticity. After passing its melting point, a strain hardening event occurs, that is, there is an addition of strain without being followed by a significant addition of voltage. In modeling, these hardening strain events are considered horizontal straight lines. After the strain hardening phase has passed the stress-strain behavior begins to deviate from each other which is characterized by lower ductility of steel for higher quality. In the analysis, the stress-strain curve of steel can be modeled and predicted using the equation:

$$\boldsymbol{\sigma_s = f_y \left[\frac{m\,(\varepsilon_s - \varepsilon_s) + 2}{60\,(\varepsilon_s - \varepsilon_s) + 2} + \frac{(\varepsilon_s - \varepsilon_s)(60 - m)}{2\,(30 - 1)^2}\right]}$$

$$\textbf{Where},\ \boldsymbol{m = \frac{f_u/f_y\,(30_r + 1)^2 - 60_r - 1}{15_r{}^2}}$$

$$\text{Dan},\ \boldsymbol{r = \varepsilon_{su}/\varepsilon_{sh}}$$

Price ε_{sh} among 1-4%.

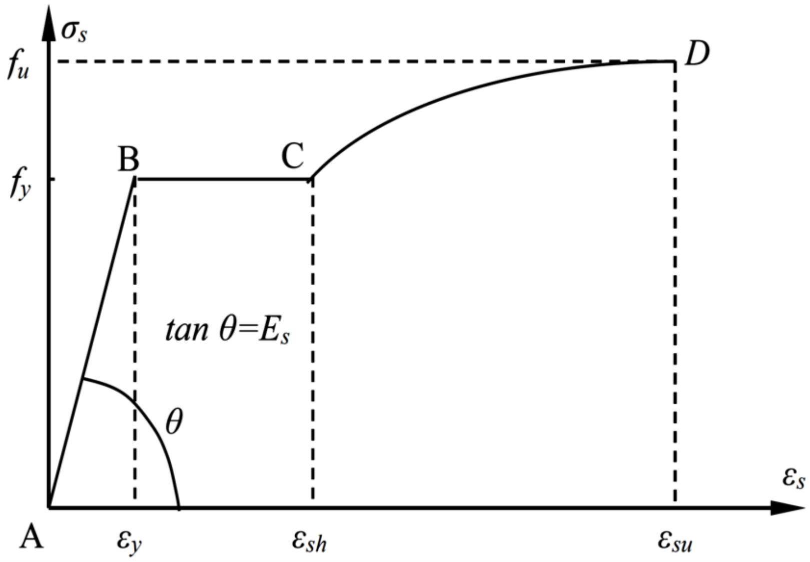


Figure 2.22 Idealization of Steel Strain Stress Curve

Based on SNI 2847-2019 article 20.2.2.2, the modulus of elasticity of non-prestressed reinforcement (Ice) can be taken in the amount of 200000 MPa. The thermal coefficient for steel reinforcement is generally the $11{,}5.10 - 6/oC$. However, to facilitate the value of steel is sometimes taken equal to the value "ɑ" of concrete, that is, $\alpha s = 10.10 - 6/oC$.

In design, the stress-strain properties of steel reinforcement can be idealized in the form of bilinear stress-strain. In addition to single steel reinforcement, in the structural elements of the plate or wall, wire mesh reinforcement is often also used which consists of a collection of plain steel wires or threads welded to each other so as to form a grid pattern. This mesh wire reinforcement generally has a minimum melting stress of 500 MPa. The wire diameter sizes available on the market are D4, D5, D6, D8, and D10. The standard size of mesh wire sheets is generally 5.4 m x 2.1 m. (Antonius, 2021)

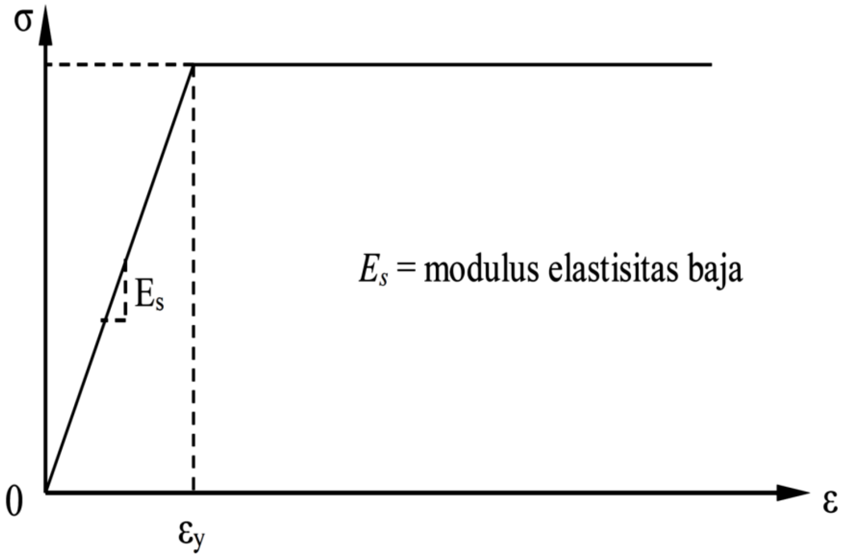


Figure 2.23 Steel Bilinear Stress-Strain Curve

2.17.2 Bonding Properties Between Concrete and Reinforcing Steel

The bonding properties between concrete and reinforcing steel play a significant role in determining the performance of reinforced concrete. The performance of reinforced concrete is closely related to the length of channeling, the length of passage (splicing), cracking and deflection. Of these four things, the length of distribution, the length of passage and cracking are influenced by the bonding properties between concrete and reinforcing steel. The role of bonding becomes dominant in the seismic behavior of reinforced concrete structures with the addition of the above factors. Bond also affects the rigidity and dissipation capacity of seismic energy.

The attachment mechanism between concrete and reinforcement consists of:

- Adhesion properties, namely the contribution of cement attachment and reinforcement.
- Friction is the contribution of the roughness of the interface between concrete and reinforcement.
- Interlocked, in the form of donations from the screw locking effect on reinforcement.

According to Antonius (2021), of the three mechanisms mentioned above, the interlocked mechanism is the most dominant. The attachment behavior between concrete and reinforcement is usually expressed in the connection of attachment stress vs slip. Based on the picture, threaded reinforcing steel has better properties than plain reinforcement, especially in terms of attachment stress. The bonding behavior of reinforcing steel to cyclic loads is different from its attachment behavior to static loads. Due to cyclic loads, the loading mechanism is in a state of attraction and pressure and takes place repeatedly so that between the concrete and the reinforcement, slip is easy which can result in faster degradation of the attachment stress. The results of the research that has been carried out revealed that threaded type reinforcement has a better attachment behavior than plain reinforcement. The behavior of attachment to cyclic loads is influenced by several factors such as concrete compressive strength (fc'), blanket thickness and reinforcement rod distance, reinforcement size/diameter, channeling length, geometry of deform rods (ribs), melting stress (fy).

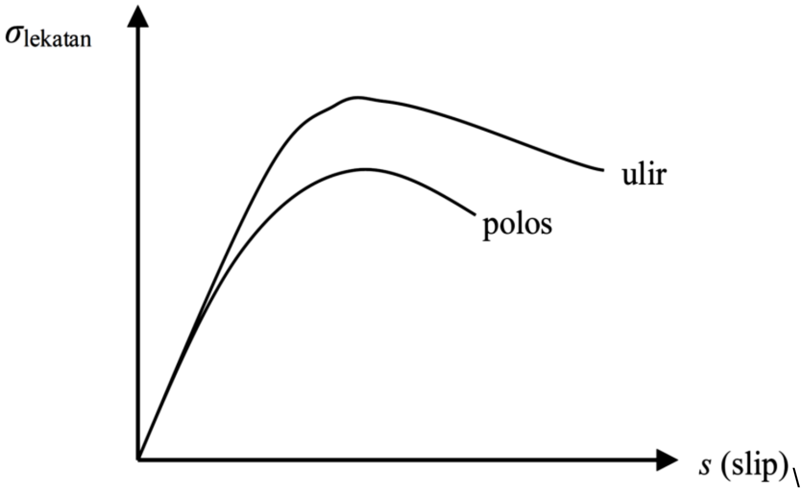


Figure 2.24 Attachment Response of Screw and Plain Steel to Static Loads

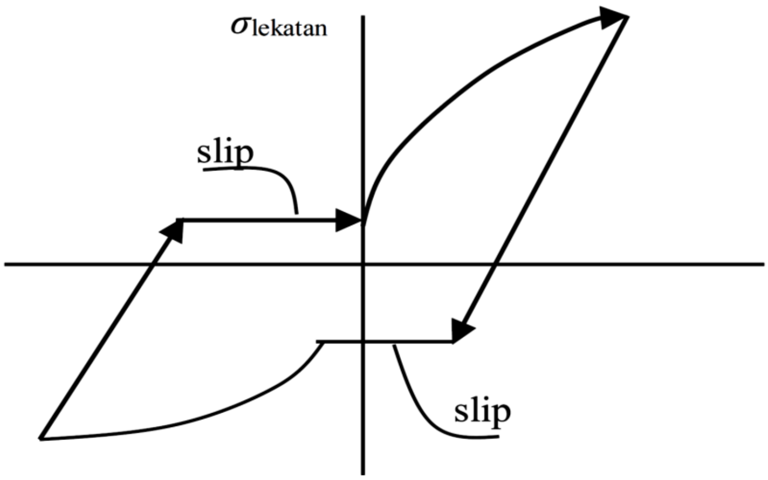


Figure 2.25 Steel Attachment Response to Cyclic Loads

2.18 BENDING ON SQUARE BEAMS

2.18.1 Bending Mechanism on Beams

Antonius 2021 suggests that in the components of structures subject to bending applies Bernoulli's law where the strain distribution along the cross-sectional height can be assumed to be linear. Based on the theory of material mechanics, due to the bending moment M in a cross section there will be a bending voltage which can be written as follows:

$$\boldsymbol{\sigma} = \frac{\boldsymbol{M} \cdot \boldsymbol{y}}{\boldsymbol{I}}$$

Where y is the distance from the neutral line to the outermost fiber and I is the cross-sectional inertia. The theory applies only to cross-sections of reinforced concrete that have not yet cracked.

The inner forces as shown in Figure 2.26, if there are no outer axial forces acting on the prevailing cross section:

$M = Cjd, or\ M = T.jd\ and\ C - T = 0 \rightarrow C = T.$

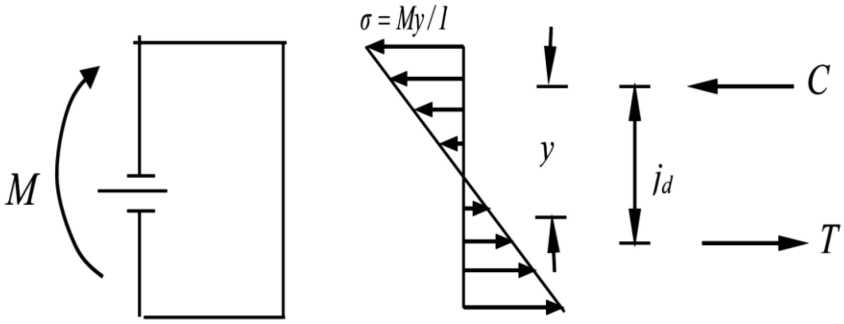


Figure 2.26 Deep-Force Mechanism Acting on Reinforced Concrete

According to Antonius (2021), the theory of bending stress in the beam above, namely $\sigma = My/I$, is not used in the design of reinforced concrete blocks because the stress-strain relationship of concrete press is non-linear, and the presence of steel reinforcement in cross section that serves to transfer tensile force when cracking occurs in cross section. Basically, the design against bending in reinforced concrete is to obtain a structure that behaves ductile. Longitudinal reinforcement plays a major role in determining the flexibility behavior of structural elements.

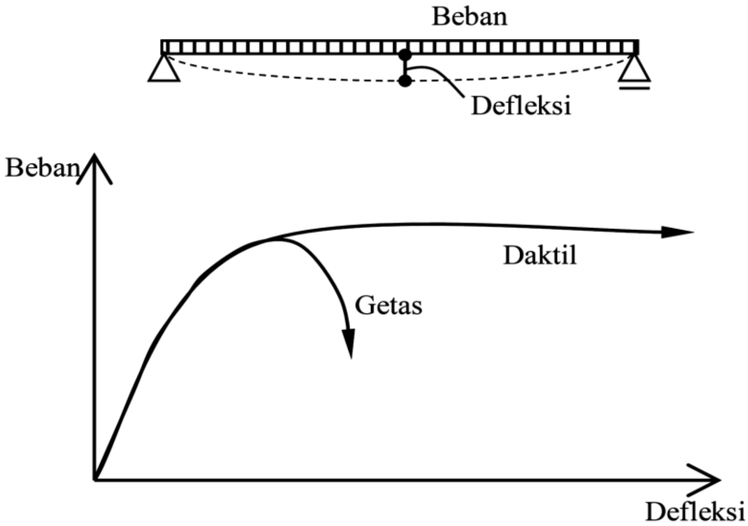


Figure 2.27 Load Relationship vs Deflection of Bending Beams

At the initial moment, where the crack has not yet occurred, the strain value that occurs as a result of the working moment is very small, so the voltage distribution obtained is still basically linear (point A). In this condition the relationship of moment and curvature in cross section is also linear. (Antonius, 2021)

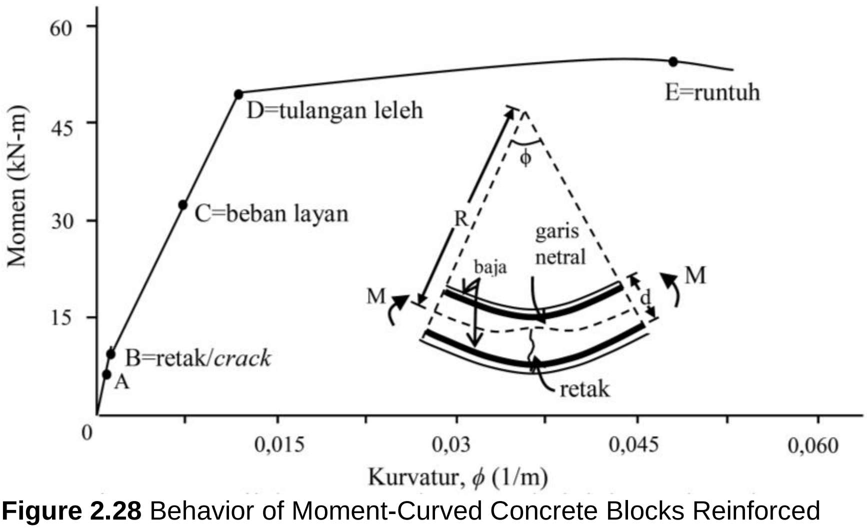


Figure 2.28 Behavior of Moment-Curved Concrete Blocks Reinforced

2.18.2 Basic Calculation of Beam Ultimate Bending Strength

Based on SNI 2847-2019 article 22.2.2.4.3 allows the use of an equivalent square compressive stress distribution for the calculation of ultimate strength. Such equivalent square compressive voltage blocks are defined as follows:

a. The compressive voltage is evenly distributed by $a_1.f'c$ (where $a_1 = 0{,}85$) assumed to work along a distanced equivalent press zone $a = \beta_1.c$ from maximum (extreme) compressive fibers.
b. Distance c from the maximum compressive fiber position to the neutral axis is measured perpendicular to that neutral axis.
c. Value β_1 taken as follows:
   - For $\mathbf{17 \leq fc' \leq 28\ MPa}$; $\boldsymbol{\beta_1 = 0{,}85}$
   - For $\mathbf{28 < f'c < 55\ MPa}$ $\boldsymbol{\beta_1 = 0{,}85 - \frac{0{,}05\ (fc'-28)}{7}}$
   - For $\mathbf{f'c\ 55\ MPa}$; $\boldsymbol{\beta_1 = 0{,}65}$

From the above equation, two parameters are required, namely a_1 and β_1 to be able to describe the equivalent square compressive voltage block. Based on the distribution of such stresses, bending strength is calculated as follows:

$$\boldsymbol{C = 0{,}85.f'c.b.a} \qquad \boldsymbol{T = A_s\,.f_y}$$

Inside the equation above the reinforcement is assumed to melt before the concrete is destroyed. The equilibrium condition → C = T so that:

$$\boldsymbol{a = \frac{A_s\,.f_y}{0.85.f'_c.b}}$$

$$\boldsymbol{M_n = A_s.f_y.\left(d - \frac{a}{2}\right)}$$

$$\boldsymbol{M_n = A_s.f_y.\left(d - 0{,}59\frac{A_s.f_y}{f'_c.b}\right)}$$

2.18.3 Types of Bending Collapse

1. **Tension Failure**

   In collapses of this type, the reinforcement melts before the concrete disintegrates (it reaches its compressive limit strain). The collapse of this type occurs in cross section with a small ratio of reinforcement. This system of recurrence of beams undergoing collapse is called “under-reinforced”.

2. **Compression Failure**

   In this collapse, the concrete disintegrates before the reinforcement melts. Such a collapse occurs in cross section with a large ratio of reinforcement. This system of repeating blocks that undergo collapse is called "over-reinforced".

3. **Balanced Collapse (Balance Failure)**

   In the collapse of this type, concrete crumbles and the reinforcement melts simultaneously. Under these conditions the melting strain of the installed tensile reinforcement occurs simultaneously with the strain of the concrete ultimate in the compressed fibers. A beam repeating system like this has a balanced reinforcement.

(Antonius, 2021)

2.19 ANALYSIS AND DESIGN OF REINFORCED CONCRETE CROSS-SECTION

Antonius (2021) suggested that there are basically two types of calculations that are usually carried out in reinforced concrete studies, namely:

2.19.1 Analysis

In the analysis, it contains calculations of cross-sectional capacity based on cross-sectional data, concrete compressive strength, steel melting stress, size and number of the reinforcement, and the location of reinforcement.

2.19.2 Design

In the design, it contains the selection of an optimum cross section (including the selection of dimensions of $f'c, fy$, reinforcement and others.) to withstand the influence of factored loads (such as Mu).

In planning against bending, it must be met:

$$\emptyset \boldsymbol{Mn} \geq \boldsymbol{M}$$

ϕ Mn = Strong bending plan

Mu = Moment ultimate necessary or strong bending need

Mn = Nominal moment capacity

ϕ = Strength reduction factor (for bending ϕ =0,90)

2.19.3 Square Beam Analysis with Tensile Reinforcement

According to Antonius (2021), to analyze the nominal moment of cross-section, a voltage distribution is shown at the cross section of the beam as shown in Figure 2.29. In Figure 2. 29, press force C, on concrete:

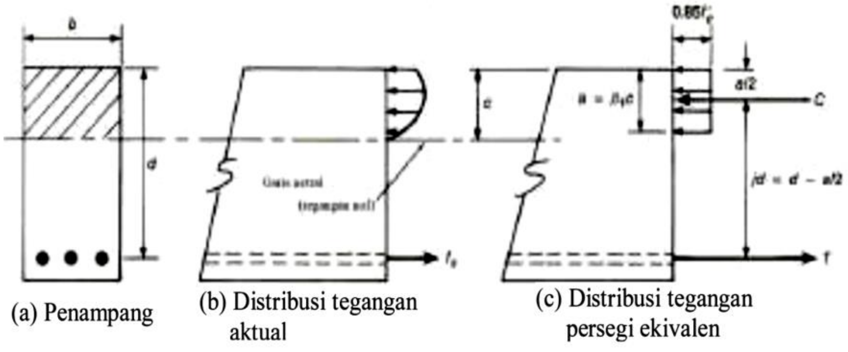


Figure 2.29 Voltage Distribution on Beam Cross-Section

If the reinforcement is assumed to melt, then $T = As.fy$

Horizontal force balance requires:

$$\boldsymbol{C = T}$$

$$\boldsymbol{0,85.f'c.a.b = As.fy}$$

$$\boldsymbol{a = \frac{A_s.f_y}{0,85.f'_c.b}}$$

$$\boldsymbol{= \frac{\omega\, d}{0,85}}$$

$$\text{Where,} \quad \boldsymbol{\omega = \frac{\rho.f_y}{f'_c}} \quad \text{dan} \ \boldsymbol{\rho = \frac{A_s}{b.d}}$$

The nominal moment (Mn) can be calculated as follows:

- $\boldsymbol{Mn = T.jd}$

$$\boldsymbol{Mn = A_s.f_y\left(d - \frac{a}{2}\right)} \rightarrow \emptyset \boldsymbol{Mn} = \emptyset\left[\boldsymbol{A_s f_y\left(d - \frac{a}{2}\right)}\right]$$

- $\boldsymbol{Mn = C.jd}$

$$\boldsymbol{Mn = 0,85.f'c.a.b\left(d - \frac{a}{2}\right)}$$

$$\rightarrow \emptyset \boldsymbol{Mn} = \emptyset\left[\boldsymbol{0,85.f'c.a.b\left(d - \frac{a}{2}\right)}\right]$$

- The above equation in another form can be written:

$$\emptyset \boldsymbol{Mn} = \emptyset[\boldsymbol{f'_c.b.d^2.\omega(1 - 0,59.\omega)}]$$

<u>Check the reinforcement has melted or not</u>

On the derivation of the previously determined Mn equation, it is assumed that the reinforcement melts (fs=fy). This assumption should be checked whether it is true. For this check, it is necessary to calculate the compressive height (=c) at the balanced state.

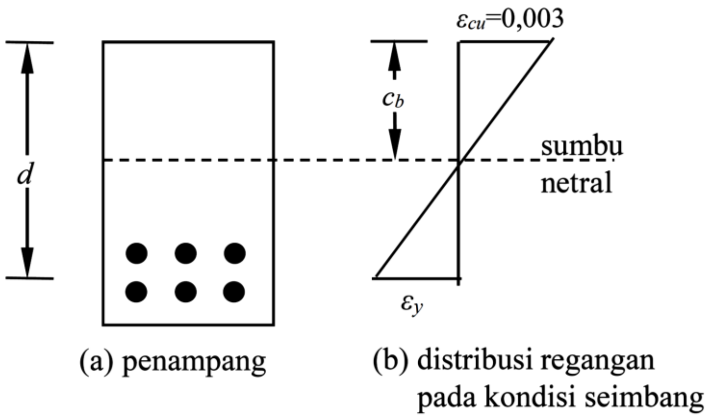


Figure 2.30 Concrete Cross-Section Strain Distribution under Repeating Conditions

Cb = High pressure area at balanced conditions

Based on the comparison of triangles (Figure 2.30):

$$\frac{C_b}{d} = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_y} = \frac{0,003}{0,003 + \frac{f_y}{200000}}$$

$$\frac{C_b}{d} = \frac{600}{600 + f_y}$$

If $a_b = \beta_1 . c$, then:

$$\frac{a_b}{d} = \beta_1 \left(\frac{600}{600 + f_y} \right)$$

f_y in MPa

To check if fs=fy, (ab/d) should be compared to (a/d), as follows:

If, $\left(\frac{a}{d}\right) \leq \left(\frac{a_b}{d}\right) \rightarrow$ then $f_s = f_y$

If, $\left(\frac{a}{d}\right) > \left(\frac{a_b}{d}\right) \rightarrow$ then $f_s < f_y$

Based on the foregoing, the type of collapse in reinforced concrete blocks depends on the ratio of reinforcement that the cross section has. Therefore, there is a rebar ratio where the collapse that will occur is balanced.

At balanced conditions:

$$a_b = \frac{A_s . f_y}{0,85. f'_c . b} = \frac{\rho_b . f_y . d}{0,85. f'_c} \quad \text{Where} \quad \rho_b = \frac{A_s}{b.d}$$

Because $a_b = \beta_1 . c_b$, then:

$$\frac{c_b}{d} = \frac{\rho_b . f_y}{0,85. \beta_1 . f'_c}$$

If this value is substituted in the previous cb/d equation then:

$$\rho_b = \frac{0,85. \beta_1 . f'_c}{f_y}\left(\frac{600}{600 + f_y}\right)$$

Based on this equation, it can also be determined whether the reinforcement has melted ($fs = fy$);

- If $\rho < \rho_b$ → the condition of the reinforcement is weak (under-reinforced), then $fs = fy$
- If $\rho > \rho_b$ → strong (over-reinforced) rebar condition, or fs $< fy$

2.19.4 Square Beam Design

According to Antonius (2021), basically the goal to be achieved in the design of reinforced concrete structures is to obtain concrete cross-sectional dimensions as well as reinforcement which include diameter, melting stress (fy) and the number of repeating. Because concrete is weak in resisting tensile and steel is very strong in resisting tensile, the reinforcement is placed in the concrete pull area which functions as the main reinforcement or often referred to as tensile reinforcement or basic reinforcement.

1. Minimum Cross-Sectional Dimensions

Based on SNI 2847:2019 For non-prestressed beams that do not rest or are attached to partitions or other constructions that may be damaged as a result of large deflection, the overall thickness of the h plate should not be less than the minimum limit in Table 9.3.1.1, unless the count result at the deflection limit of 9.3.2 is met.

Table 2.12 Minimum Cross-Sectional Dimensions

Kondisi perlekatan	Minimum h[1]
Perlekatan sederhana	$\ell/16$
Menerus satu sisi	$\ell/18{,}5$
Menerus dua sisi	$\ell/21$
Kantilever	$\ell/8$

[1] Rumusan dapat diaplikasikan untuk beton mutu normal dan tulangan mutu 420. Untuk kasus lain, minimum h harus dimodifikasi sesuai dengan 9.3.1.1.1 hingga 9.3.1.1.3, sebagaimana mestinya.

Source: Table 9.3.1.1 SNI 2847:2019

For fy greater than 420 MPa, the equation in Table 9.3.1.1 must be multiplied by (0,4 + fy / 700).

2. Minimum Reinforcement

Based on SNI 2847-2019 section 9.6.1.2 AS, min must be greater than a) and b), unless provided 9.6.1.3. For certain static beams with wings in a tensile state, the value of bw must be smaller than bf and 2bw.

$$a)\quad \frac{0{,}25\sqrt{f'_c}}{f_y} b_w d \quad \text{and} \quad b)\quad \frac{1{,}4}{f_y} b_w d$$

In T beams where the beam body part is subjected to tensile, the ratio ρ should be calculated based on the width of the beam body.

3. Square Beam Design with Tensile Reinforcement

According to Antonius (2021), The requirements that must be met in the design of square blocks are:

$$\boldsymbol{\phi Mn \geq Mu}$$

As mentioned earlier the moment of the factored prisoner can be calculated:

$$\boldsymbol{\phi Mn = \phi[f'_c . b . d^2 . \omega(1 - 0,59 . \omega)]}$$

$$\boldsymbol{\omega = \llbracket \rho . f \rrbracket \_y / f\_c'}$$

According to Antonius (2021), In the equation above there are 6 unknown numbers, namely: b, d, ρ, fy, fc' and MD, and 2 equations ϕMn and *MD* as a function rather than a cross-sectional dimension. There-fore the block design process will not result in a unique product/solution. To obtain a design solution, 4 assumptions relating to unknown design parameters are required. For a start, we need to make assumptions regarding the compressive strength of concrete (fc') and the melting stress of the steel to be used. Usually there are durability conditions that must be met in the selection of concrete quality. In addition, it is also necessary to pay attention to the contractor's ability to produce concrete of a certain quality. The fc' values typically used range from 20-40 MPa. As for reinforcing steel, the quality that is usually used is reinforcing steel with $fy = 400\ MPa$. By the know of fc' and $fy,$ only 3 variables need to be determined, they are *b, h* and *ρ*. If *b* and *h* known, we can directly calculate *ρ*. But if *b* and *h unknown, then the value b* and *d* can be estimated by the following relationships:

$$\boldsymbol{b.d^2 = \frac{Mu}{\phi[f'_c.\omega(1-0,59.\omega)]}}$$

Based on SNI 2847-2013 appendix B.10.3 limits the ratio of reinforcement $\rho \leq 0{,}75\ \rho b$. How-ever based on experience it is better to limit the ratio of *reinforcement* ρmax by $0{,}4 – 0{,}5\rho b$. By limiting ρmax between $0{,}5 – 0{,}75\ \rho b$, then the *ratio of* a/d cross-section is also limited in range between:

$$\boldsymbol{0{,}5\ \frac{a_b}{d} - 0{,}75\,\frac{a_b}{d}}$$

2.20 "T" BEAM

In general, T beams can be divided into *edge beams (exterior*) and middle beams (interior). With this condition, the concrete slab will serve as the upper wing of the beam. The T beam repeating culprit follows the shape of the moment that occurs mainly in the area experiencing the pull. Basically, the T beam can behave as a T beam at the time of holding the positive moment and behave as an ordinary square beam at the time of holding the negative moment. The behavior of the T beam crack begins in the central region of the span, which then expands to the fulcrum area according to the type of moment that occurs. (Antonius, 2021

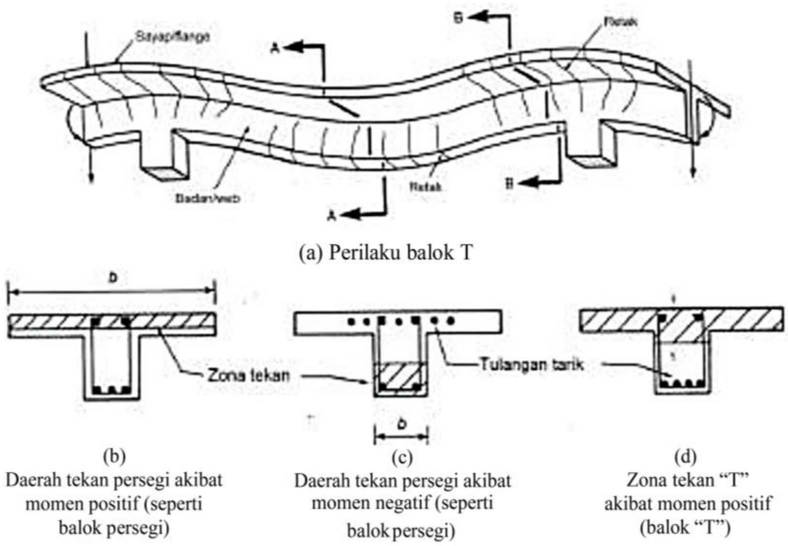


Figure 2.31 Positive and Negative Moment Area T Beam

2.20.1 Effective Wingspan

a. T Beams Are Not Separated

Pursuant to SNI 2847:2019 art. 6.3.2.1 For non-prestressed T-Beams made fused (monoliths) or composite slabs, the effective width of the bf wing shall include the width of the bw beam body plus the effective width of the overhanging wing as per Table 6.3.2.1, where h is the thickness of the plate and sw is the net distance between the adjoining beams.

Table 2.13 Limitations of Effective Wingspan Dimensions U For T-Beams

Lokasi sayap	**Lebar sayap efektif, di luar penampang balok**	
Kedua sisi balok	Sekurangnya:	$8h$
		$s_w/2$
		$\ell_n/8$
Satu sisi balok	Sekurangnya:	$6h$
		$s_w/2$
		$\ell_n/12$

Source: SNI 2847:2019

b. Separate / Independent T Beam

Based on SNI 2847:2019 article 6.3.2.2 Separate non-prestressed T-beams, where the T-wing is required to increase the area of the compressive area, must have a wing thickness of not less than or equal to $0.5b_w$ and the effective width of the wing not more or equal to $4b_w$.

Table 2.14 Thickness and Effective Wingspan for Separate T-Beams

Thick Wings	$h \geq 0,5\ b_w$
Effective Wingspan	$bf \leq 4b_w$

Source: SNI 2847:2019

2.20.2 T Beam Analysis

According to Antonius (2021), there are two possible locations of the line that occur in the T beam, namely the neutral line is located on the wing and the neutral line is located on the body. If the pressure zone of the T beam is square then for a case like this, the T beam can be analyzed as a square beam with a width of b. For cases where the T-shaped pressure zone or neutral line is located on the body, the analysis can be carried out by taking into account separately the contribution of the wing and the cross-sectional body in holding the moment.

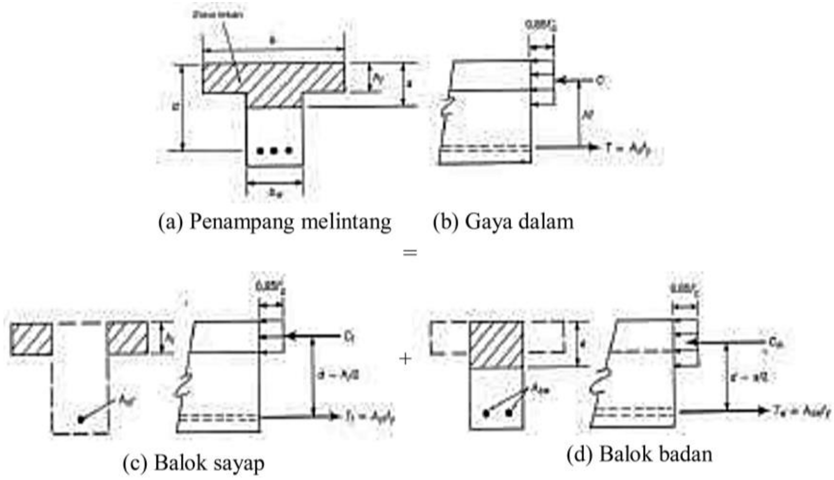


Figure 2.32 T Beam Analysis (Antonius, 2021)

Analysis of the T beam if the neutral line is located on the body is carried out separately as follows:

- Wing Beams

  Area of compressive zones:

$$(\boldsymbol{b} - \boldsymbol{b_w})\boldsymbol{h_f}$$

  Press force:

$$\boldsymbol{C_f = 0,85. f'_c. (b - b_w)h_f}$$

  Balance terms $Tf = Cf$

  So by assuming melting reinforcement (fs=fy) then:

$$\boldsymbol{A_{sf}. f_y = 0,85. f'_c. (b - b_w)h_f}$$

or,

$$\boldsymbol{A_{sf} = \frac{0,85. f'_c. (b - b_w)h_f}{f_y}}$$

  Moment arm:

$$\boldsymbol{M_{nf} = 0,85. f'_c. (b - b_w)h_f \left(d - \frac{h_f}{2}\right)}$$

$$\boldsymbol{M_{nf} = A_{sf}. f_y \left(d - \frac{h_f}{2}\right)}$$

- Body Beams

  Area of reinforcement Pull body:

$$A_{sw} = A_s . A_{sf}$$

Press force:

$$C_w = 0,85. f'_c . b_w . a$$

Balance terms:

$$C_w = T_w = A_{sf} . f_y$$

So that:

$$a = \frac{A_{sf} . f_y}{0,85. f'_c . b_w}$$

The moment arm is ($d - a/2$), so that:

$$M_{nw} = 0,85. f'_c . b_w . a\left(d - \frac{a}{2}\right)$$

or,

$$M_{nw} = A_{sw} . f_y\left(d - \frac{a}{2}\right)$$

Moments on the beam T= Moments on the wing beam + Moments on the body beam.

$$M_n = M_{nf} + M_{nw}$$

$$M_n = \left[A_{sf} . f_y\left(d - \frac{h_f}{2}\right) + A_{sw} . f_y\left(d - \frac{a}{2}\right)\right]$$

1. Check Reinforcement Melting ($f_s = f_y$)

According to Antonius (2021), The value of fs in the previously mentioned analysis is assumed that the reinforcement melts (fy). This assumption must be checked, by comparing the value (a/d) of the calculation result against the value (ab/d), i.e.:

$$\frac{a_b}{d} = \beta_1\left(\frac{600}{600 + f_y}\right), \quad \text{If,}$$

$\left(\frac{a}{d}\right) \leq \left(\frac{a_b}{d}\right)$ then, $f_s = f_y$

2. **T Beam Maximum Reinforcement**

Based on SNI 2847:2019, it requires:

$$\rho \leq 0,75\ .\ \rho_b$$

According to Antonius (2021), If the compression zone on the T-shaped beam is T- shaped, it is necessary to calculate the area of the tensile reinforcement associated with balanced collapse, that is,:

$$A_{sb} = \frac{C_b}{f_y} \rightarrow C_b = 0,85 . f'_c . \left[(b - b_w)h_f + b_w . a\right]$$

So that,

$$A_{maks} \leq 0,75\ A_{sb}$$

3. **Minimum Reinforcement T Beam**

Based on SNI 2849-2019 article 9.6.1.2. The minimum reinforcement limit requirement for T-beams is:

$$A_{s,min} = \frac{\sqrt{f'_c}}{4 . f_y} . b_w . d \geq \frac{1,4}{f_y} b . d$$

and

$$A_{s,min} = \frac{\sqrt{f'_c}}{4 . f_y} . b_f . d$$

2.21 BEAMS WITH PRESS REINFORCEMENT

2.21.1 Effect of Compressive Reinforcement on Beam Strength

According to Antonius (2021), MacGregor (1997) outlines some of the advantages obtained by the use of compressive reinforcement as follows:

- Reducing event p-term deflection
- Improves ductility
- Changing the type of compressive collapse to a striated t collapse
- Simplify implementation

2.21.2 Beam Analysis with Tensile and Compressive Reinforcement

According to Antonius (2021), In the analysis of double reinforced beams (tensile and compressive) divided /broken into:

1. Beam I, which consists of compressive reinforcement and tensile reinforcement with a sufficient amount so that T1=Cs
2. Beam II, which consists of a concrete compressive area and the rest of the tensile reinforcement $(As2 = As - As1)$

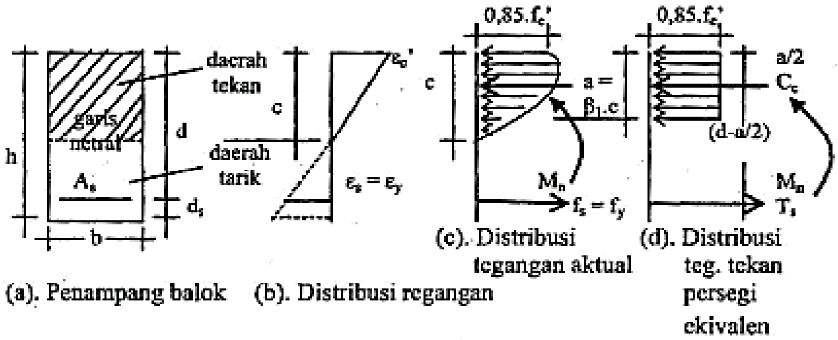


Figure 2.33 Strain and Stress Distribution of Single Reinforcement Beams (Asroni, 2010)

In the picture of the strain distribution above, it can be proved that:

$$\boldsymbol{\varepsilon_s}' = \left(\frac{\boldsymbol{c - d'}}{\boldsymbol{c}}\right)\boldsymbol{.0{,}003}$$

By taking $\varepsilon_s' = \varepsilon_y$ and $\varepsilon_y = f_y/200000$, then value (d'/a) the limit at which the compressive reinforcement will melt is:

$$\left(\frac{\boldsymbol{d'}}{\boldsymbol{a}}\right)_{\boldsymbol{lim}} = \frac{\boldsymbol{1}}{\boldsymbol{\beta_1}}\left(\boldsymbol{1} = \frac{\boldsymbol{f_y}}{\boldsymbol{600}}\right)$$

- If the value $\left(\frac{d'}{a}\right) > \left(\frac{d'}{a}\right)_{lim} \rightarrow$ non-melting compressive reinforcement

- If the value $\left(\frac{d'}{a}\right) \leq \left(\frac{d'}{a}\right)_{lim} \rightarrow$ melting compressive reinforcement

If the reinforcement is melted compressive, the calculation of the capacity analysis of the cross-sectional moment will be easier than if the compressive reinforcement does not melt. (Antonius,2021)

a. Melting Press Reinforcement

- Beam I

  The required area of tensile reinforcement is calculated based on the equilibrium conditions Cs = T1, so that:

  $$A_s{}'.f_y = A_s1.f_y \text{ or } A_s1 = A_s{}'$$

  Beam moment capacity:

  $$M_n1 = A_s{}'.f_y(d - d')$$

- Beam II

  Area of residual reinforcement = $A_s2 = A_s - A_s1$

  If the reinforcement pulls melt then:

  $$T_2 = (A_s - A_s1).f_y = (A_s - A_s')$$

  Concrete compressive force:

  $$C_c = 0{,}85.f_c{}'.a.b$$

  Based on the balance of style $C_c = T_2$ then:

  $$a = \frac{(A_s - A_s').f_y}{0{,}85.f_c{}'.b}$$

  Nominal moment capacity:

  $$M_n2 = T_2\left(d - \frac{a}{2}\right) = (A_s - A_s').f_y\left(d - \frac{a}{2}\right)$$

  Nominal moment of total cross-section of double-reinforced concrete:

  $$M_n = M_n1 + M_n2$$

$$M_n = A_s'.f_y(d-d') + (A_s - A_s').f_y\left(d - \frac{a}{2}\right)$$

To prove $f'_s = f_y$ then it is worth checking whether:

$$\left(\frac{d'}{a}\right) \leq \left(\frac{d'}{a}\right)_{lim}$$

And for $f_s = f_y$ needs to be checked:

$$\left(\frac{a}{d}\right) \leq \left(\frac{a_b}{d}\right)_{lim}$$

b. Non-Melting Press Reinforcement

Assumptions → Reinforcement The melting pull then the force in the beam:

$$T = A_s.f_y$$

$$C_c = 0,85.f_c\,'.a.b$$

$$C_s = (E_s.\varepsilon_s').A_s'$$

Where, $\varepsilon'_s = \left(1 - \frac{\beta_1.d'}{a}\right).0,003$

Equation of axial forces of cross section:

$$C_c + C_s = T$$

This equation produces quadratic equations in a:

$$(0,85.f_c\,'.b).a^2 + \left(0,003.E_s.A_s\,' - A_s.f_y\right).a - (0,003.E_s.A_s\,'.\beta_1.d') = 0$$

Capacity of the cross-sectional moment:

$$M_n = C_c.\left(d - \frac{a}{2}\right) + C_s.(d - d')$$

The above quadratic equations only apply if $f_s' \leq f_y$. To prove the correctness of assumptions $fs = fy$, needs to be checked:

$$\left(\frac{a}{d}\right) \leq \left(\frac{a_b}{d}\right)$$

1. **Maximum Tensile Reinforcement Ratio for Beams to Press Reinforcement**

Based on SNI 2847:2019, the maximum limit of tensile reinforcement:

- $f'_s = f_y$

$$\rho_{max} = 0,75.\rho_b$$

$$\text{Where,}\quad (\rho - \rho')_b = \frac{0,85.f_c{}'.\beta_1}{f_y}\left(\frac{600}{600 + f_y}\right)$$

- $f'_s < f_y$

$$\rho_{max} = 0,75.\rho_b$$

$$\text{Where,}\quad \left(\rho - \frac{\rho'.f'_s}{f_y}\right)_b = \frac{0,85.f_c{}'.\beta_1}{f_y}\left(\frac{600}{600 + f_y}\right)$$

2.22 REINFORCED CONCRETE BLOCK DESIGN AGAINST SHEAR FORCES

2.22.1 Cracks in Reinforced Concrete Blocks

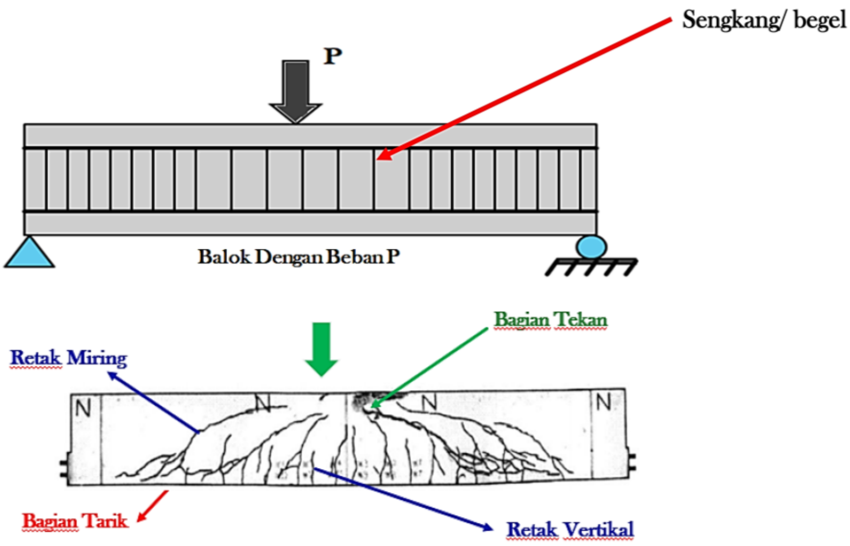


Figure 2.34 Cracking Mechanism on Reinforced Concrete Blocks (Sudarno, 2022)

1. Vertical Cracks

According to Sudarno (2022), Oblique cracking occurs due to the failure of the beam in withstanding shear loads, so it usually occurs in the end area (near the fulcrum) of the beam because in this area the largest shear force / latitude force arises.

2. Oblique Cracks

According to Sudarno (2022), In general, vertical cracking occurs due to the failure of the beam in withstanding flexible loads, so it usually occurs in the field area (middle span) of the beam, because in this area the largest bending moment arises.

2.22.2 Beam Cracking Due to Shear Force

Sudarno (2022) stated that itis possible to give a fairly clear picture of the work of the shear force / latitude force on the beam, so it is done by taking a small element of concrete that is in the end area of the beam as shown in the figure below.

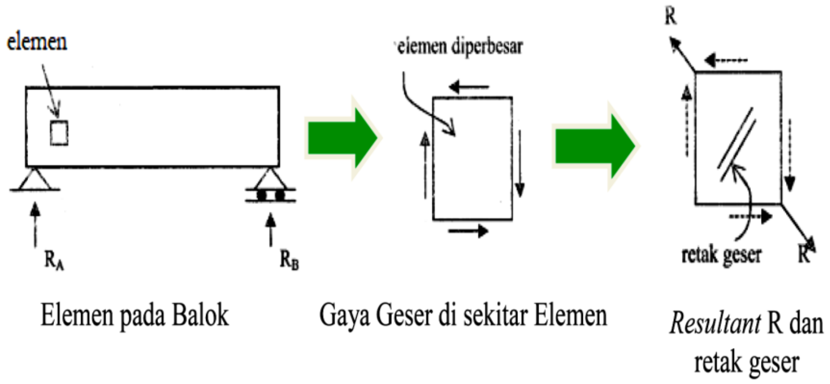


Figure 2.35 Beam Shear Elements and Forces
(Sudarno, 2022)

a. Shear forces around the elements according to Sudarno (2021):
   - The direction of the RA reaction is upwards, so that on the surface of the plane of the left element a shear force occurs with an upward direction.
   - The concrete element is in a stable state, a vertical force balance occurs in the concrete element, so that on the surface of the plane of the element on the right arises a downward shear force, the shear force on both sides is the same.
   - Due to the upward shear force on the surface of the plane of the left and right directions, the concrete element will arise a moment whose direction corresponds to the clockwise direction.
   - The concrete element is in a stable state, so the moment that exists must be in the opposite of another moment of the same magnitude but the opposite direction.

b. Resultant R and shear crack according to Sudarno (2021):
   - The upward shear force on the surface of the left plane and the shear force to the left on the upper plane surface form a resultant (R) its direction is tilted to the left-up.
   - The upward shear force on the right plane surface and the rightward shear force on the lower plane surface form a resultant (R) its direction is tilted to the left-down.
   - From item 1 and item 2 the resultant values are the same, but in the opposite direction and mutual attraction.

- Concrete elements will crack in an inclined direction forming an angle $a = 45°$, if the element is unable to withstand the tensile force of both resultants (R).

2.22.3 Overcoming Shear Cracks

According to Sudarno (2021), Oblique cracks in the beam can be resisted by 4 elements, namely as follows:

1. The shape and roughness of the surface of the concrete aggregate (sand and gravel). Aggregates that are sharp in shape / cornered and rough surfaces are very strong to withstand the shear force because the aggregates are interlocking, thus making it difficult for slips (not easily cracked). If the aggregate is round and the surface is smooth, it is not strong enough to withstand the shear force, because it is easy to slip (easy to crack).
2. The shear crack is restrained by the pulling force and dowel action of the longitudinal reinforcement.
3. The shear cracks are held by concrete struts
4. The shear crack is restrained by the pulling force of the shear reinforcement, both in the form of oblique reinforcement and tiled reinforcement.

2.22.4 Shear Reinforcement Installation

According to Sudarno (2022) Shear reinforcement on beams can be installed in an inclined direction (oblique reinforcement or oblique reinforcement) and in an upright direction (bubbly or sting).

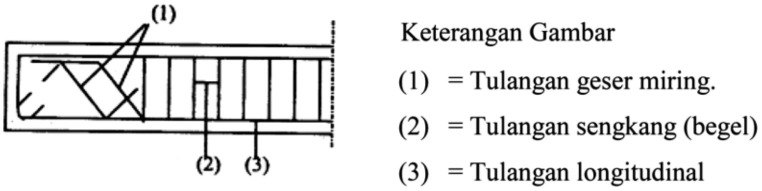


Figure 2.36 Shear Reinforcement and Longitudinal Beams

The types of tiles that are commonly used are distinguished by the number of legs, namely: 2-foot tiles, 3-foot tiles, and 4-foot tiles.

Figure 2.37 Types of Tiles on Beams

2.22.5 Beam Shear Reinforcement Planning

Based on Sudarno (2022), Planning tiles beam can be done with the following steps:

1. The shear force of the plan, nominal shear force, shear force held by the concrete begel is formulated by:

$$Vr = \phi . Vn;\ dan\ \phi . Vn \geq Vu$$

$$Vn = Vc + Vs$$

Where:

Vr = Shear force plan, (kN)

Vn = Nominal Shear Strength, (kN)

Vc = Shear forces held by concrete, (kN)

Vs = The shear force resisted by the tiles (kN)

ϕ = Shear reduction factors = 0,75

2. The value of Vu can be taken at a distance of d (being Vud) from the face of the column formulated as follows:

$$Vud = Vut + (x/y).(Vu - Vut)$$

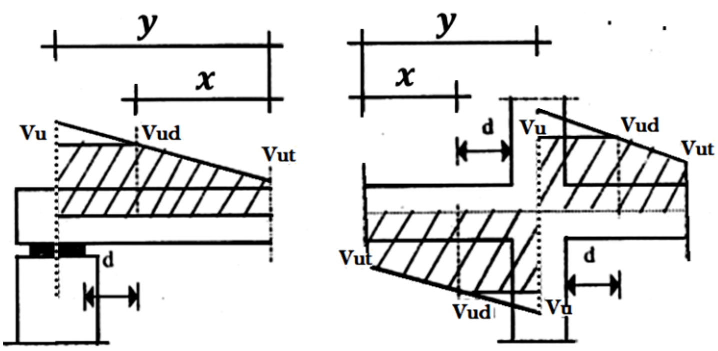


Figure 2.38 Vu Value Mechanism

3. The shear force resisted by concrete (Vc) is calculated by:

$$\boldsymbol{V_c = \frac{1}{6} . \sqrt{f'_c} . b . d}$$

4. The shear force held by the begel (Vs) can be calculated by the equation:

$$\boldsymbol{V_s = \frac{(V_u . \phi . V_c)}{\phi}} \qquad \boldsymbol{V_s = \frac{A_v . f_y . d}{s}} \quad \boldsymbol{s = \text{Stirrups Distance}}$$

5. For conditions if:

   Vs must $\leq\ 2/3\sqrt{fc'}.b.d$

   If Vs turns out $>\ 2/3.\sqrt{fc'}.b.d$ then the size of the beam should be enlarged.

2.23 REINFORCED CONCRETE SLABS

According to Sudarno (2022) Reinforced Concrete Slabs are thin structures made of reinforced concrete with planes that are in a horizontal direction, and the load that acts perpendicularly on the plane of the structure.

Reinforced Concrete Slabs are widely used in civil buildings both as**:**

- Building Floors
- Roof floor of a Building
- Bridge Floor / Floor on the Pier
- Cor Roads

2.23.1 Slab Fulcrum

Sudarno (2022) stated that in planning slabs, it is necessary to pay attention to the type of placement and the type of linkage in the fulcrum. The rigidity of the relationship between the plate and the fulcrum will determine the magnitude of the bending moment that occurs on the plate. For building buildings, generally the slabs are pedestaled by the beams:

1. **Monolith**

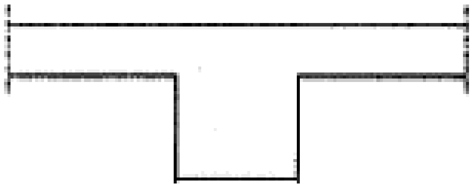


Figure 2.39 Monolith (Sudarno, 2022)

2. **Rested by The Walls of The Building**.

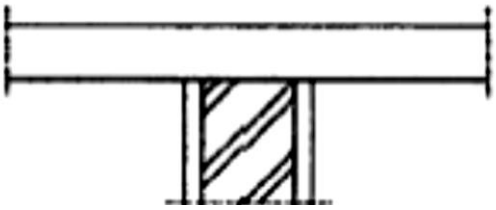


Figure 2.40 Slab Resting on The Wall (Sudarno, 2022)

3 **The Slabs are Supported by Steel Beams with a Composite System.**

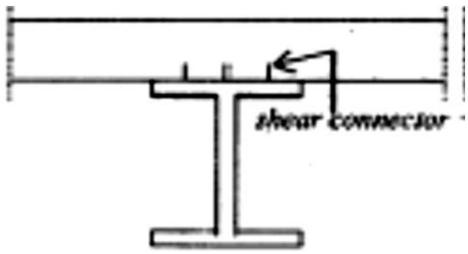


Figure 2.41 Slabs are Superimposed Steel Beams with a Composite System (Sudarno, 2022)

4 **Slab Supported by Columns Directly without Beams**

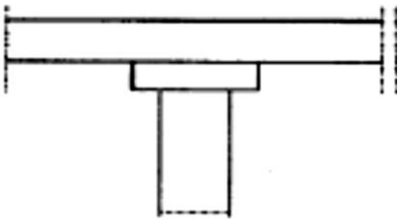


Figure 2.42 Slab are Supported by Columns Directly without Beams (Sudarno, 2022)

2.23.2 Types of Slab Placement

According to Sudarno (2022) there are 3 types of plate placement on beams including:

1. Freely Located

This situation occurs if the plate is simply placed on the beam, or between the plate and the beam is not cast together, so that the plate can rotate freely on the pedestal.

Figure 2.43 Slabs are Located Free (Sudarno, 2022)

2. Elastic Pinched

This circumstance occurs If the Slabs and Beams are cast together in a monolith, but the size of the beams is small enough, so the beams are not strong enough to prevent rotation from occurring.

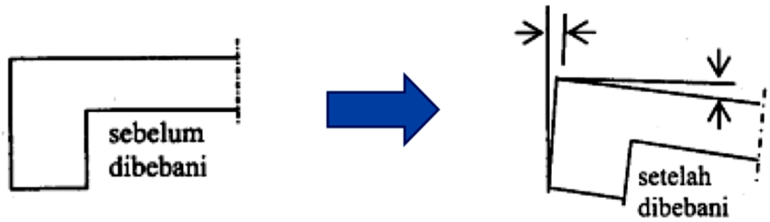


Figure 2.44 Elastic Clamped Slab (Sudarno, 2022)

3. Fully Pinched

This situation occurs If the Slabs and Beams are cast together in a monolith, the size of the beams is large enough, so as to be able to prevent the rotation of the slabs.

Figure 2.45 Fully Pinched Slab (Sudarno, 2022)

2.23.3 Slab System

In general, the ratio value of the long side (b) and the short side (a) of the plate becomes the differentiator of the floor plate system, namely:

- One-way slabs when b/a > 2.0 and in the design analysis it is carried out in 1 direction, namely the direction of the short side.
- Two-way slabs when 1.0 ≤ b/a ≤ 2.0 and in analysis it is carried out in 2 directions, namely the x and y directions.

2.24 ONE-WAY SLAB DESIGN

2.24.1 Design Limitations

According to SNI 2847:2019 article 7.3.1.1 For non-prestressed solid slabs that do not rest or are attached to partitions or other constructions that may be damaged as a result of large deflection, the overall thickness of the plate h should not be less than the minimum limit in Table 7.3.1.1, unless the result of the count at the deflection limit of 7.3.2 is met.

Table 2.15 Minimum Thickness of Non-Prestressed One-Way Solid Slab

Kondisi tumpuan	h[1] Minimum
Tumpuan sederhana	$\ell/20$
Satu ujung menerus	$\ell/24$
Kedua ujung menerus	$\ell/28$
Kantilever	$\ell/10$

[1]Angka ini berlaku untuk beton berat normal dan f_y = 420 MPa. Untuk kasus lain, ketebalan minimum harus dimodifikasi sesuai 7.3.1.1.1 hingga 7.3.1.1.3.

Source: Table 7.3.1.1 SNI 2847:2019

Based on SNI 2847:2019 For fy over 420 MPa, the equation in Table 7.3.1.1 must be multiplied by $(0{,}4 + fy\ /\ 700)$ and for non-prestressed slabs made of lightweight concrete with wc ranging from $1440\ to\ 1840\ kg/m^3$, the equation in Table 7.3.1.1 should be multiplied by the largest values of a) and b):

a) $1,65 - 0,0003wc$

b) $1,09$

2.24.2 Strength Needs

Pursuant to SNI 2847:2019 section 7.4 The force needs to be calculated in accordance with the combination of burdens taken into account in Article 5 and shall be in accordance with the procedure for analysis in Article 6.

The necessary force U must include the influence of the internal load due to the reaction generated by the prestress force with a load factor of 1.0.

2.24.3 Design Strength

Based on SNI 2847:2019 article 7.5.1.1 For each combination of factored loads used, the design strength in all cross sections must meet $\varphi Sn \geq U$ including a) and b). The interaction between the influences of the load must be taken into account.

a) $\phi Mn \geq Mu$

b) $\phi Vn \geq Vu$

2.24.4 Reinforcement Limitations

a. Minimum Bending Reinforcement

The minimum area of flexible reinforcement, As,min, must be provided as per Table 7.6.1.1 SNI 2847:2019.

Table 2.16 As-min for Non-Prestressed One-Way Slabs

Tipe tulangan	f_y, MPa	$A_{s,min}$	
Batang ulir	< 420	$0{,}0020A_g$	
Batang ulir atau kawat las	≥ 420	Terbesar dari:	$\frac{0{,}0018\times 420}{f_y}A_g$
			$0{,}0014A_g$

Source: Table 7.6.1.1 SNI 2847:2019

- For slabs with glued prestressed reinforcement, the total number of Axles and Aps must be sufficient to develop a factorized load of at least 1.2 times the crack load calculated based on fr.
- For slabs with tendons without attachment, the minimum longitudinal threaded reinforcement area, As, min, should be:

$$\boldsymbol{As, min \geq 0,004\, Act}$$

Where the Act is the area of the cross section that is on the pull side to the point of weight of the gross cross section.

b. Minimum Shear Reinforcement

Based on SNI 2847:2019 article 7.6.3.1 The minimum area of shear reinforcement $Av.min$, must be provided at all cross sections where $Vu > \phi Vc$. For hollow precast slabs without cover concrete $h > 315\ mm, Av.min$ should be provided in all cross sections where $Vu > 0{,}5\phi Vcw$.

2.24.5 Rebar Details

a. Reinforcement Spacing (SNI 2847:2019 article 7.7.2)

- Minimum spacing s must match the article 25.2 SNI 2847:2019
- The maximum spacing s for threaded reinforcement should be less than 3h and 450 mm.
- The reinforcement space required by 7.5.2.3 must not exceed the smallest value of 5h and 450 mm.

b. Flexural Reinforcement of Non-Prestressed Slabs

- The reinforcement must be passed past the point where it is no longer needed to hold the bending with at least the greatest distance from d and 12db, except on simple pedestals and cantilevers.
- Bending tensile reinforcement channeling should have a channeling length of at least ld past the point where the bent or broken tensile reinforcement is no longer needed to withstand bending.
- Bending tensile reinforcement should not be broken in the tensile area unless a), b), or c) is met:
  $Vu \leq (2/3)\ \phi Vn$ at the break point (cutoff).
  For reinforcement D36 or smaller, the area of the reinforcing passed on is twice the area required to bend at the break-off point and $Vu \leq (3/4)\ \phi Vn$.
  The excess sting area required for shearing is provided along the break of the reinforcement or wire up to 3/4d of the break point of the reinforcement. The area of excess sting should not be less than $0{,}41 bw\ s/fyt$. S spaces cannot exceed $d/(8\beta b)$.

c. **Termination of Reinforcement (SNI 2847:2019 Article 7.7.3.8)**

On simple pedestals and turning points, db for positive moment attraction reinforcement should be limited to such an extent that ℓd can meet a) or b). If the reinforcement is cut off past the centerline of the fulcrum with the end of a standard hook or mechanical hoisting that is at least equivalent to a standard hook, a) or b) it does not need to be met.

- $\ell d \leq (1{,}3Mn / Vu + \ell a)$ if the ends of the reinforcement are restrained by the press reaction.
- $\ell d \leq (Mn / Vu + \ell a)$ if the end of the reinforcement is not restrained by the compressive reaction.

Mn is calculated assuming all reinforcing stresses at the cross-section reach fy and Vu is calculated at that cross section. On a pedestal, ℓa is the length of the channeling that passes through the center of the fulcrum. At the turning point, la is the length of the channeling that passes the turning point, delimited by the largest value of d or 12db.

2.24.6 Approach Methods for The Analysis of Continuous Beams and One-Way Slabs

Under SNI 2847:2019 section 6.5.1 To calculate Mu and Vu due to gravity loads it is permissible to use this provision for continuous beams and one-way slabs provided that a) to e) is met:

a) The components of the structure are prismatic
b) Evenly distributed load
c) The unfactored live load does not exceed three times the unfactored dead load (L ≤ 3D)

d) There are two or more spans

e) The length of the largest span against the shortest span length of the two adjoining spans is no more than 20 %.

Based on SNI 2847:2019 article 6.5.2 Mu due to gravity load must be calculated based on SNI Table 6.5.2. The Moment and shear approach provides conservative values for certain conditions if the continuous beams and one-way slabs are part of a continuous frame or construction. Since the load pattern that produces the critical value for the moments on the column of the frame is different from that which produces the maximum negative moments on the beam, the moments of the columns should be evaluated separately.

According to SNI 2847:2019 Moments calculated according to 6.5.2 should not be redistributed and ***Vu*** due to gravity load must be calculated based on the table below:

Table 2.17 Shear Approach to The Analysis of Continuous Beams and Non-Prestressed One-Way Slabs

Lokasi	V_u
Muka eksterior dari pendukung muka interior pertama	$1{,}15 w_u \ell_n/2$
Muka dari pendukung lainnya	$w_u \ell_n/2$

Source: Table 6.5.4 SNI 2847:2019

Table 2.18 Moment of Approach to The Analysis of Continuous Beams and Non-Prestressed One-Way Slabs

Momen	Lokasi	Kondisi	M_u
Positif	Bentang ujung	Ujung tak menerus dan monolit dengan perletakan	$w_u \ell_n^2/14$
		Ujung tak menerus dan tidak terkekang	$w_u \ell_n^2/11$
	Bentang tengah	Semua	$w_u \ell_n^2/16$

Negatif[1]	Muka interior dari pendukung eksterior	Balok menyatu secara monolit dengan balok spandrel pendukung	$w_u \ell_n^2/24$
		Balok monolit dengan kolom pendukung	$w_u \ell_n^2/16$
	Muka eksterior dari pendukung interior pertama	Dua bentang	$w_u \ell_n^2/9$
		Lebih dari dua bentang	$w_u \ell_n^2/10$
	Muka dari pendukung lainnya	Semua	$w_u \ell_n^2/11$
	Muka semua pendukung memenuhi (a) atau (b)	(a) Pelat dengan bentang tidak lebih dari 3 m (b) Balok dengan rasio jumlah kekakuan kolom terhadap kekakuan balok melebihi 8 pada setiap ujung bentangnya	$w_u \ell_n^2/12$
[1]Untuk menghitung momen negatif, ℓ_n harus diambil rata-rata panjang bentang bersih bersebelahan			

Source: Table 6.5.2 SNI 2847:2019

2.25 TWO-WAY SLAB DESIGN

2.25.1 Design Limitation

Table 2.19 Minimum Thickness of Non-prestressed Two-Way Slabs without Interior Beams (mm)[1]

f_y, MPa[2]	Tanpa *drop panel*[3]			Dengan *drop panel*[3]		
	Panel eksterior		Panel interior	Panel eksterior		Panel interior
	Tanpa balok tepi	Dengan balok tepi[4]		Tanpa balok tepi	Dengan balok tepi[4]	
280	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$	$\ell_n/36$	$\ell_n/40$	$\ell_n/40$
420	$\ell_n/30$	$\ell_n/33$	$\ell_n/33$	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$
520	$\ell_n/28$	$\ell_n/31$	$\ell_n/31$	$\ell_n/31$	$\ell_n/34$	$\ell_n/34$

[1]ℓ_n adalah jarak bersih ke arah memanjang, diukur dari muka ke muka tumpuan (mm)
[2]Untuk f_y dengan nilai diantara yang diberikan dalam tabel, ketebalan minimum harus dihitung dengan interpolasi linear
[3]*Drop panel* sesuai 8.2.4
[4]Pelat dengan balok di antara kolom sepanjang tepi eksterior. Panel eksterior harus dianggap tanpa balok pinggir jika α_f kurang dari 0,8. Nilai α_f untuk balok tepi harus dihitung sesuai 8.10.2.7

Source: Table 8.3.1.1 SNI 2847:2019

Table 2.20 Minimum Thickness of Non-Prestressed Two-Way Slabs with Beams Between the Pedestals on All Their Sides

α_{fm} [1]	*h* minimum, mm		
$\alpha_{fm} \leq 0,2$	8.3.1.1 berlaku		(a)
$0,2 < \alpha_{fm} \leq 2,0$	Terbesar dari:	$\dfrac{\ell_n\left(0,8 + \dfrac{f_y}{1400}\right)}{36 + 5\beta\left(\alpha_{fm} - 0,2\right)}$	(b)[2],[3]
		125	(c)
$\alpha_{fm} > 2,0$	Terbesar dari:	$\dfrac{\ell_n\left(0,8 + \dfrac{f_y}{1400}\right)}{36 + 9\beta}$	(d)[2],[3]
		90	(e)

Source: Table 8.3.1.2 SNI 2847:2019

2.25.2 Strength Needs

Pursuant to SNI 2847:2019 section 8.4.1.1 The force needs to be calculated in accordance with the combination of the factored load in Article 5 and section 8.4.1.2 The force needs to be calculated in accordance with the analysis procedure given in Article 6 as an alternative:

- The moment of the factored plate held by the column

  SNI 2847:2019 art. 8.4.2.3.2 The magnitude of the moment fraction of the factored plate held by the column, $\gamma f Msc$, should be regarded as channeled as pliable, where γf must be calculated with:

$$\boldsymbol{\gamma f = \frac{1}{1+\left(\frac{2}{3}\right)\sqrt{\frac{b1}{b2}}}}$$

Effective width of plate slabs for holding $\gamma f Msc$ should be as wide as a column or column head plus 1.5h of plate or drop panel on either side of the column or column head.

Table 2.21 Maximum Modified Value γf for Two-Way Slabs Non-Prestressed

Letak kolom	**Arah bentang**	v_{ug}	ε_t **(termasuk** b_{pelat}**)**	**Modifikasi** γ_f **maksimum**
Kolom sudut	Salah satu arah	$\leq 0,5\phi v_c$	≥0,004	1,0
Kolom tepi	Tegak lurus tepi	$\leq 0,75\phi v_c$	≥0,004	1,0
	Sejajar tepi	$\leq 0,4\phi v_c$	≥0,010	$\frac{1,25}{1+\left(\frac{2}{3}\right)\sqrt{\frac{b_1}{b_2}}} \leq 1,0$
Kolom interior	Salah satu arah	$\leq 0,4\phi v_c$	≥0,010	$\frac{1,25}{1+\left(\frac{2}{3}\right)\sqrt{\frac{b_1}{b_2}}} \leq 1,0$

Source: Table 8.4.2.3.4 SNI 2847:2019

2.25.3 Strength Design

Based on SNI 2847:2019 article 8.5.1.1 For each applicable factored combination load, the design strength must meet $\phi Sn \geq U$, and includes a) to d). The relationship between the influences of the load should be considered.

a) $\phi Mn \geq Mu$ in all cross sections along the span in each direction.

b) $\phi Mn \geq \gamma f Msc$ in slabs as defined in 8.4.2.3.3.

c) $\phi Vn \geq Vu$ in all cross-sections along the span in each direction for one-way sliding.

d) $\phi vn \geq vu$ at critical cross-section defined in 8.4.4.1 for two-way sliding.

2.25.4 Reinforcement Limitation

Based on SNI 2847:2019 section 8.6.1.1 The minimum area of the reinforcement, As, min, shall be provided near the tensile advance in the direction of the span reviewed as per Table 8.6.1.1.

Table 2.22 As, min for Non-Prestressed Two-Way Slabs

Jenis Tulangan	f_y, MPa	$A_{s,min}$, mm^2	
Batang ulir	< 420	$0{,}0020A_g$	
Batang ulir atau kawat las	≥ 420	Terbesar dari:	$\frac{0{,}0018 \times 420}{f_y} A_g$
			$0{,}0014A_g$

Source: Table 8.6.1.1 SNI 2847:2019

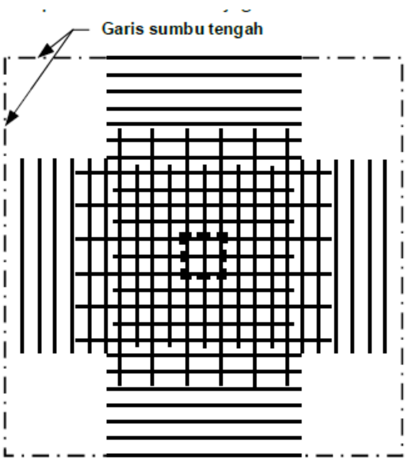


Figure 2.46 Minimum Reinforcement Arrangement Near the Top of The Two-Way Slab (Figure R8.6.1.1 SNI 2847:2019)

Pursuant to SNI 2847:2019 article 8.6.2.3 For prestressed slabs, the minimum area of glued longitudinal thread reinforcement, As, min, shall be provided at the tensile area originally depressed in the direction of the span reviewed as per Table 8.6.2.3.

Table 2.23 As, min for Prestressed Two-Way Slabs

Daerah	f_t terhitung setelah semua kehilangan prategang, MPa	$A_{s,min}$, mm^2	
Momen positif	$f_t \leq 0{,}17\sqrt{f_c}'$	Tidak disyaratkan	(a)
	$0{,}17\sqrt{f_c}' < f_t \leq 0{,}50\sqrt{f_c}'$	$\frac{N_c}{0{,}5 f_y}$	(b)[1],[2],[4]
Momen negatif kolom	$f_t \leq 0{,}5\sqrt{f_c}'$	$0{,}00075 A_{cf}$	(c)[3],[4]

Source: Table 8.6.2.3 SNI 2847:2019

2.25.5 Reinforcing Details

a. Spacing of Flexible Reinforcement

Based on SNI 2847:2019 article 8.7.2.2 For non-prestressed solid slabs, the maximum spacing of the longitudinal thread reinforcement must be the smallest of $2h$ and 450 mm at critical cross-sections, and the smallest of $3h$ and 450 mm in other cross sections and article

8.7.2.3 For prestressed slabs with even loads, the maximum spacing of s tendons or tendon groups in at least one direction should be the smallest of 8h and 1.5 m.

b. Slab Angle Resistance

According to SNI 2847:2019 article 8.7.3.1 At the angle of the exterior plate rested by the edge wall or when one or more edge beams having an αf greater than 1.0, the upper and lower reinforcement of the plate must be designed to hold the Mu per unit width due to the influence of an angle equal to the maximum positive moment of Mu per unit width on the plate panel.

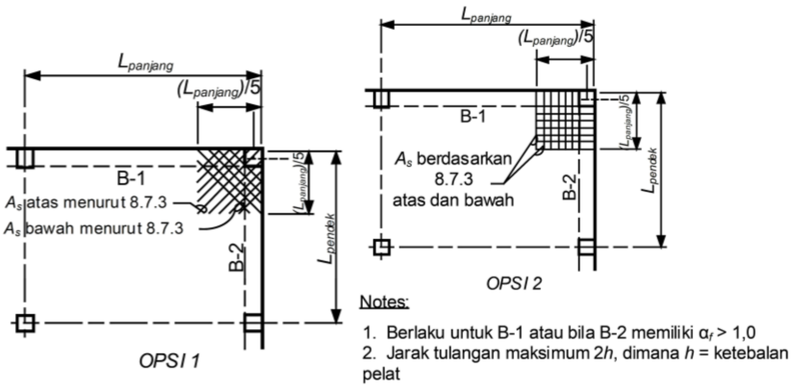


Figure 2.47 Minimum Reinforcement Arrangement Near the Top of The Two-Way Slab (SNI 2847:2019)

c. Thread Reinforcement

According to SNI 2847:2019 article 8.7.5.6.3.1 The minimum lower threaded reinforcement of the As in each direction must be the largest of a and b:

$$a)\ A_s = \frac{0,37\sqrt{f'c}\ bwd}{f_y}$$

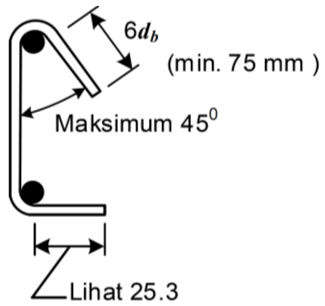
$$b)\ A_s = \frac{2,1\ bwd}{f_y}$$

d. Shear Reinforcement and Stirrups

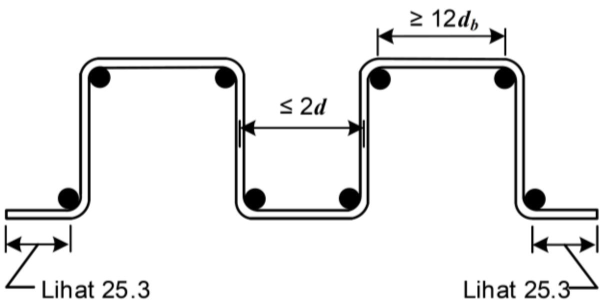
Table 2.24 Location Limits and First Space Stirrups

Arah pengukuran	**Deskripsi pengukuran**	**Jarak atau spasi maksimum, mm**
Tegak lurus dengan muka kolom	Jarak dari muka kolom ke sengkang pertama	$d/2$
	Spasi antar sengkang	$d/2$
Sejajar dengan muka kolom	Spasi antara kaki vertikal sengkang	$2d$

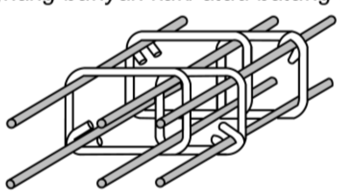
Source: Table 8.7.6.3 SNI 2847:2019



(a) sengkang satu kaki atau batang tulangan



(b) sengkang banyak kaki atau batang tulangan



(c) sengkang tertutup

Figure 2.48 Single- or Multiple-Leg Stirrups - Plate Type Shear Reinforcement
(SNI 2847:2019)

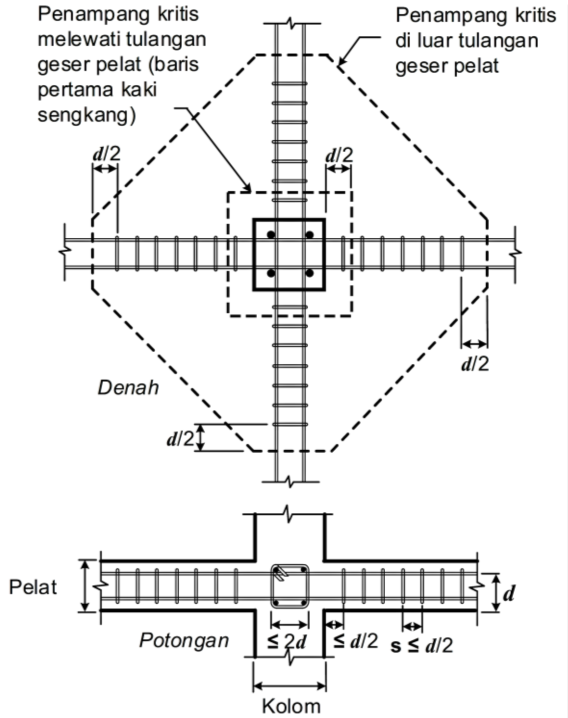


Figure 2.49 Arrangement of Shear Stirrups Reinforcement for Interior Columns
(SNI 2847:2019)

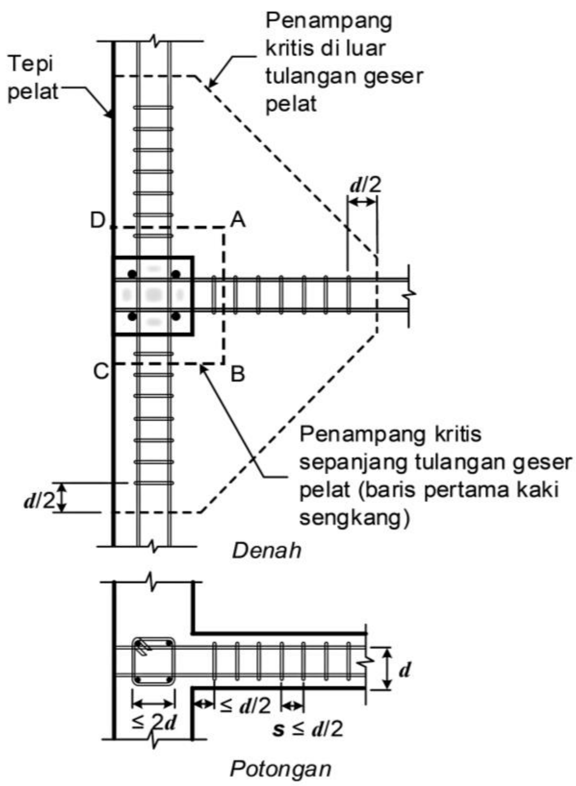


Figure 2.50 Setting of Edge Column Shear Stirrups Reinforcement
(SNI 2847:2019)

2.26 COLUMN DESIGN

According to Sukma Idham Laksana (2021) a column is a component of a vertical structure that serves to carry a compressive axial load (with or without a bending moment). The columns should be designed to withstand axial forces as well as loading conditions that result in the maximum moment of the reactor load on all floors or roofs. In calculating the moment of gravitational load on the column it is allowed to assume the ends of the constructed column fused with the structure as pinched

2.26.1 Design Limitation

Based on SNI 2847:2019 article 18.7.2 The columns must meet a) and b):

1. The dimensions of the smallest cross section, measured on a straight line through the center of geometry, are not less than 300 mm.
2. The ratio of the dimensions of the smallest cross section to its perpendicular dimensions is not less than 0.4.

2.26.2 Minimum Bending Strength of Columns

Based on SNI 2847:2019 article 18.7.3 The bending strength of the column must meet:

$$\sum \boldsymbol{M_{nc}} \geq (\mathbf{1,2}) \sum \boldsymbol{M_{nb}}$$

2.26.3 Longitudinal Reinforcement

Based on SNI 2847:2019 article 10.6.1:

1. For non-prestressed columns and prestressed columns with average values$f_{pe} < 1{,}6\ MPa$, the longitudinal reinforcement area must be at least 0.01Ag, but it cannot exceed 0.08Ag.

2. For composite columns with structural steel cores, the longitudinal reinforcement area that is inside the transverse reinforcement must be at least $0{,}01(Ag - Asx)$, but must not exceed $0{,}08(Ag - Asx)$.

Based on SNI 2847:2019 article 18.7.4:

1. Luas The area of longitudinal reinforcement Ast should not be less than 0.01Ag and not more than 0.06Ag.
2. On columns with a rounded sting, the minimum number of longitudinal reinforcement rods should be 6.

2.26.4 Transversal Reinforcement

Based on SNI 2847:2019 Transversal reinforcement required by sections 18.7.5.2 to 18.7.5.4 must be installed along the o length of each joint face and on both sides of any cross section where bending melting is possible to occur as a result of lateral displacement that goes beyond the elastic behavior. The length of o should not be less than the largest value between a) to c):

a) The height of the column on the joint face or in cross section where bending melting is possible.
b) 1/6 Net height of the column.
c) 450 mm.

According to SNI 2847:2019 article 18.7.5.2 Transverse reinforcement must be appropriate a) to f):

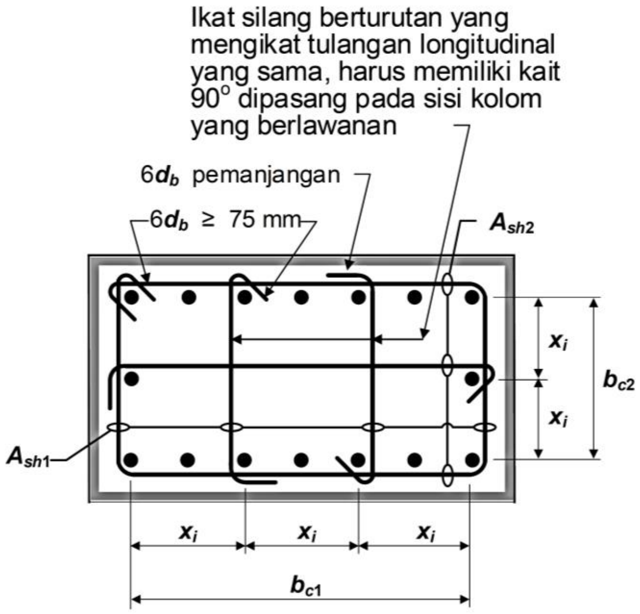
a) Transverse reinforcement should consist of a single spiral or spiral stacked (overlap), a round restraint zinc, or a square restraint zinc, with or without cross-tie.
b) Each bend of the ends of the square restraint and cross-tie must hook the outermost longitudinal reinforcement rod. Cross-tie with the same size of the reinforcing rod or smaller than the diameter of the restraint zinc is allowed

as per the 25.7.2.2 limit. Successive cross-connecting should be crisscrossed ends along longitudinal reinforcement and around the perimeter of the cross section.

c) If a square restraint or cross-tie is used, the transverse reinforcement must serve as a lateral fulcrum for longitudinal reinforcement according to 25.7.2.2 and 25.7.2.3.

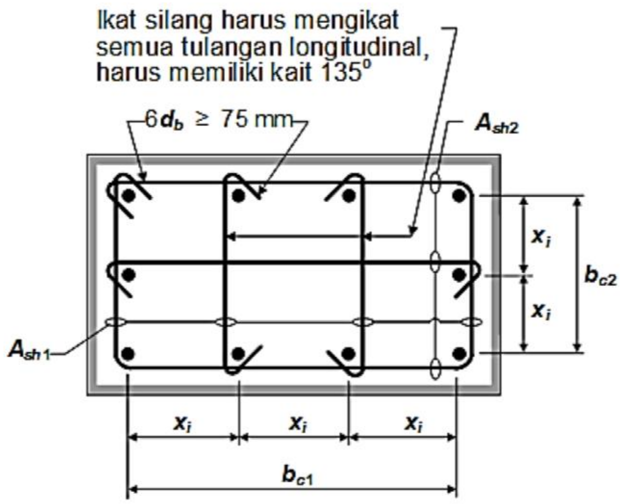
d) The reinforcement should be arranged in such a way that the hx spacing between the longitudinal reinforcements along the cross-sectional perimeter of the column laterally superimposed by the cross-connecting angle or the legs of the restraint should not exceed 350 mm.

e) When $Pu > 0{,}3Agfc'$ or $fc' > 70\ MPa$ in columns with restraint stings, each rod or bundle of longitudinal reinforcement around the perimeter of the column core must have a lateral pedestal given by the angle from the stirrup restraint or by an earthquake hook and the hx value should not exceed 200 mm. Pu should be the largest compressive force consistent with the combination of factored loads including E.



Dimensi x_i antara sumbu-sumbu penampang tulangan longitudinal yang ditopang secara lateral tidak melebihi 350 mm. Nilai h_x dalam Pers. (18.7.5.3) diambil sebagai nilai terbesar dari x_i.

Figure 2.51 Example of Transverse Reinforcing on a Column (SNI 2847:2019)



Dimensi x_i antara sumbu-sumbu penampang tulangan longitudinal yang ditopang secara lateral tidak melebihi 200 mm. Nilai h_x dalam Pers. (18.7.5.3) diambil sebagai nilai terbesar dari x_i.

Gambar 2.52 Example of Transverse Reinforcing on a Column with $Pu > 0{,}3Agfc'$ or $fc' > 70\ Mpa$ (SNI 2847:2019)

Based on SNI 2847:2019 article 18.7.5.3 Transverse reinforcement space does not exceed the smallest value from (a) to (c):

a) 1/4 the smallest dimensions of the column cross section.

b) 6 x diameter of the smallest longitudinal reinforcement.

c) S_o, which is calculated with:

$$\boldsymbol{S_o = 100 + \left(\frac{350 - h_x}{3}\right)}$$

S_o should not exceed 150 mm and should not need to be less than 100 mm.

Based on SNI 2847:2019 article 18.7.5.4 The number of transverse reinforcements must be as per Table 18.7.5.4 The strength factor of concrete kf and the effectiveness factor of Kn restraint is calculated based on equations 18.7.5 4a and 18.7.5 4b

.

Table 2.25 Transverse Reinforcement for Columns of Special Moment Bearing Frame System

<table>
<tr><th>Tulangan transversal</th><th>Kondisi</th><th colspan="2">Persamaan yang berlaku</th></tr>
<tr><td rowspan="2">A_{sh}/sb_c

untuk sengkang pengekang persegi</td><td>$P_u \le 0,3A_g f_c'$
dan
$f_c' \le 70$ MPa</td><td>Terbesar antara (a) dan (b)</td><td rowspan="2">$0,3\left(\frac{A_g}{A_{ch}}-1\right)\frac{f_c'}{f_{yt}}$ (a)
$0,09\frac{f_c'}{f_{yt}}$ (b)
$0,2k_f k_n\frac{P_u}{f_{yt}A_{ch}}$ (c)</td></tr>
<tr><td>$P_u > 0,3A_g f_c'$
atau
$f_c' > 70$ MPa</td><td>Terbesar antara (a), (b) dan (c)</td></tr>
<tr><td rowspan="2">ρ_s

untuk spiral ataupun sengkang pengekang lingkaran</td><td>$P_u \le 0,3A_g f_c'$
dan
$f_c' \le 70$ MPa</td><td>Terbesar antara (d) dan (e)</td><td rowspan="2">$0,45\left(\frac{A_g}{A_{ch}}-1\right)\frac{f_c'}{f_{yt}}$ (d)
$0,12\frac{f_c'}{f_{yt}}$ (e)
$0,35k_f\frac{P_u}{f_{yt}A_{ch}}$ (f)</td></tr>
<tr><td>$P_u > 0,3A_g f_c'$
atau
$f_c' > 70$ MPa</td><td>Terbesar antara (d), (e) dan (f)</td></tr>
</table>

Source: SNI 2847:2019

2.27 FOUNDATION

Sardjono (1988) suggests that the foundation is one of the building constructions located at the bottom of a construction, the foundation has an important role in a building, where the foundation bears all the construction loads from the top to the soil layer at the bottom.

Dirjen Cipta Karya in the IPLT book stated that building foundations are generally distinguished as shallow foundations and deep foundations. The selection of the foundation can be carried out on the basis of the carrying capacity of the soil as follows:

1. If the hard soil is located at ground level or 2–3 m below the ground level, the type of foundation that can be used is a shallow foundation, namely a path foundation, a palm foundation or a manual drill pile foundation.
2. If the soil condition is soft to a depth of approximately 6 m, the type of foundation that can be used is a manual drill pile foundation.
3. If hard soil is located at a depth of about 10 m or more below the soil surface, the type of foundation that can be used is a deep foundation, namely a mini-pile pile foundation, a well foundation or a drill pile foundation.
4. If hard soil is located at a depth of 20 m or more below the soil surface, the type of foundation that can be used is the deep foundation, namely the pile foundation or the drill pile foundation.

2.27.1 Types of Foundation

Dirjen Cipta Karya in the IPLT book stated that Planning in the selection of the foundation of a building is determined based on the type of soil, strength, and carrying capacity of the soil as well as the load of the building itself. On soils that have good carrying capacity, then the foundation also requires a simple construction. If the soil is labile and has an ugly carrying capacity, then the determination of the foundation should also be more thorough. The foundation of a building construction must be able to withstand the following loads:

- Horizontal loads/ shear loads, such as loads due to ground compressive forces;
- Dead load, or the building's own weight;
- Live load, or load according to the function of the building;
- Earthquake load
- Wind load;
- Water lifting force; and
- Moment and torque.

a. Shallow Foundation

Dirjen Cipta Karya in the IPLT book stated that a shallow foundation is the bottommost building structure that serves to pass on (distribute) the load of the building to the soil layer that is relatively close to the soil surface. Shallow foundations are used when a layer of hard soil that is able to support the load of the building on it, is located close to the ground level, and is suitable for use in types of structures that are not too heavy and also not too high. The shape of the foundation is usually chosen according to the type of building and the type of soil. In general a shallow foundation can take the form of:

- foundation of the palm;
- continuous foundation;
- the foundation of the circle; and
- raft foundation.

To measure the carrying capacity of the foundation, it is necessary to analyze the carrying capacity of the foundation using Terzaghi Theory (1943), as follows:

$$\boldsymbol{qult = c\,Nc\,Sc + q\,Nq + 0{,}5\,\gamma\,B\,N\gamma\,S\gamma}$$

Where:

$qult$ = ultimate soil carrying capacity (kN/m^2)

c = soil cohesion under the foundation base (kN/m^2)

q = additional load (kN/m^2)

B = foundation width (m)

D = foundation depth (m)

φ = ground shear angle (o)

$NcNqN\gamma$ = soil carrying capacity factor

$Sc, S\gamma$ = foundation form factor

The value of the soil carrying capacity factor is a function of the magnitude of the shear angle value in the soil. Terzaghi gives recommendations for $nc, Nq\ and\ N\gamma$ values in Table 2.25.

Table 2.26 Terzaghi (1943) Soil Carrying Capacity Factor

Ø	N_c	N_q	N_γ	N'_c	N'_q	N'_γ
0°	5,71	1,00	0	3,81	1,00	0
5°	7,32	1,64	0	4,48	1,39	0
10°	9,64	2,70	1,2	5,34	1,94	0
15°	12,8	4,44	2,4	6,46	2,73	1,2
20°	17,7	7,43	4,6	7,90	3,88	2,0
25°	25,1	12,7	9,2	9,86	5,60	3,3
30°	37,2	22,5	20,0	12,7	8,32	5,4
35°	57,8	41,4	44,0	16,8	12,8	9,6
40°	95,6	81,2	114,0	23,2	20,5	19,1
45°	172	173	320	34,1	35,1	27,0

The shallow foundation has several forms. In Table 2.26 is given a recommendation of the values of $Sc\ and\ S\gamma$ by Terzaghi:

Table 2.27 Foundation Form Factor

Bentuk	S_c	S_γ
Pondasi Menerus	1,0	1,0
Pondasi Lingkaran	1,3	0,6
Pondasi Sujur Sangkar	1,3	0,8

Source: Terzaghi (1943)

b. Well Foundation

Dirjen Cipta Karya in the IPLT book stated that a well foundation, which is a transitional form between a shallow foundation and a deep foundation, is used when a strong bottom soil is located at a relatively deep depth. The foundation is also a special foundation with several conditions that are suitable for applying this well foundation, including:

- In harsh soil conditions with a foundation depth of more than 3 m, while other shallow foundations require digging too deep and wide soil.
- In areas that have a high groundwater level, considering that the construction of concrete slabs will be difficult to carry out because the water in the excavated pit must be pumped first.

For a well foundation with $Df > 5B$, the carrying capacity of the foundation can be calculated by the following formula:

$$\boldsymbol{Pu' = Pu + Ps\ Pu' = qu\ Ap + \pi\ Dfs\ Df}$$

Where:

Pu' = Total ultimate load for the deep foundation (kN)

Pu = Total ultimate load for shallow foundation (kN)

Ps = Friction resistance on the foundation wall (kN)

qu = Carrying capacity of shallow foundations (kN/m^2)

Ap = Foundation base area (m^2)

$D = B$ = Foundation width (m)

fs = Friction factor (Table 5-3)

Df = Foundation depth (m)

c. Deep Foundation

Dirjen Cipta Karya in the IPLT book stated that the foundation in a construction building has an important role because it functions as a restraint or support for the load of the building on it to be passed on to the soil layer below. To produce a strong and solid building, the foundation of a building must be well planned. Deep foundation planning must meet the following 3 conditions:

- Safety factor against collapse, both for its mast and for its supporting soil;
- A decrease in total and a different decrease from the foundation due to workload; and
- Security and stability of the surrounding buildings.

The deep foundation is selected according to the type of building and the type of soil, in general the types of deep foundations include:

1. Piles

The use of piles for a building foundation depends largely on the following conditions:

- The bottom land under the building has no carrying capacity;
- The bottom ground under the building is not capable of carrying the building that is on it or the hard ground capable of carrying that load away from the ground level;

- Development on uneven ground; and
- Meets the need to withstand the upward urging force.

2. Drill Poles

The foundation of a drill pile is a deep foundation that is built inside the soil surface to a certain depth by making holes through soil drilling. After the elevation of the drilling depth is reached then the foundation of the drill pile is carried out by casting reinforced concrete against the hole that has been drilled.