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STRUCTURAL ANALYSIS OF LINAC AND BRACHYTHERAPY BUNKER DESIGN (CASE STUDY: RADEN MATTAHER REGIONAL GENERAL HOSPITAL, JAMBI)

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ABSTRACT

The LINAC and Brachytherapy bunkers constructed at RSUD Raden Mattaher Jambi are part of a strategic healthcare development initiative by the Jambi Provincial Government. These bunker structures possess specialized characteristics to ensure maximum protection against radiation exposure, utilizing thick reinforced concrete and, in some areas, lead-lined layers. Radiation Shielding Concrete (RSC), also known as heavyweight concrete, is used for this purpose, typically having a density greater than 2600 kg/m^3. Designed to attenuate gamma rays, X-rays, and neutrons, the effectiveness of RSC depends significantly on its density. Studies indicate that concrete with densities between 3012–3820 kg/m^3 achieves linear attenuation coefficients (μ) ranging from 0.224 to 0.265 cm^{-1}, demonstrating high shielding capability. During construction, deviations occurred between the Detail Engineering Design (DED) and the actual field implementation (As-Built Drawing or ABD) due to site conditions and safety considerations. This study aims to analyze the structural differences between DED and ABD. Structural analysis was conducted using ETABS software to obtain internal forces in the structural elements, followed by manual verification. Results show that the columns are capable of resisting axial loads and moments, with reinforcement ratios within the required 1%–6% of gross concrete area (Ag). Variations in internal forces were identified between DED and ABD. In the floor slab analysis, the DED design failed to meet flexural strength requirements (Mu > ϕMn), while the ABD design achieved sufficient nominal capacity (Mu < ϕMn), enhancing the structure's performance under service loads.

Keywords: *Bunker, Structural Analysis, LINAC, Brachytherapy, Radiation Shielding Concrete*

1. INTRODUCTION

Raden Mattaher Regional General Hospital (RSUD Raden Mattaher) is a public hospital owned by the Provincial Government of Jambi, Indonesia. Among its specialized services is a radiology installation which includes advanced cancer treatment options such as radiation therapy using Linear

Accelerator (LINAC) technology and brachytherapy.

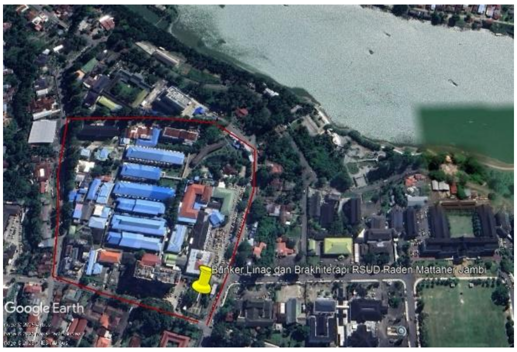


Figure 1. Project Site of the LINAC and Brachytherapy Bunker Construction

LINAC is a medical device designed to deliver high-energy external beam radiation precisely to cancerous tissues, while brachytherapy involves the placement of internal radioactive sources to treat tumors. Compared to conventional cancer treatments, radiotherapy offers the advantage of accurately targeting cancer cells while minimizing exposure to surrounding healthy tissues.

To support the safe implementation of such treatments, radiotherapy facilities require well-shielded enclosures—commonly referred to as bunkers. These bunkers are vital for ensuring the protection of patients, medical personnel, and the surrounding environment from harmful radiation. Radiation protection in bunker design is divided into two main categories: source shielding and structural shielding. Structural shielding is further classified into primary and secondary barriers. Primary barriers are designed to absorb direct radiation beams, while secondary barriers protect against scattered and leakage radiation (Wulan et al., 2022). Hence, the structural integrity and shielding effectiveness of bunkers must be meticulously designed and evaluated to comply with safety and regulatory requirements (Hutagalung et al., 2024).

In response to the increasing demand for oncology services in Jambi and surrounding regions, the Jambi Provincial Government has undertaken the construction of a dedicated radiotherapy bunker facility at RSUD Raden Mattaher. This facility is expected to become a flagship cancer treatment center in the region. The initial structural design of the bunker was developed by a professional engineering team. However, during the construction phase, several design modifications were made due to field conditions and safety considerations. As a result, it became necessary to analyze and compare the as-built structure with the initial Detail Engineering Design (DED) plan to evaluate consistency and performance.

This study aims to analyze the structural differences between the initial DED and the realized construction of the LINAC and brachytherapy bunkers at RSUD Raden Mattaher, focusing specifically on the column and slab elements. The analysis is performed using ETABS version 21.2.0 software and follows Indonesian building standards, including SNI 1727:2020 for structural loads, SNI 1726:2019 for seismic design, and SNI 2847:2019 for reinforced concrete structures.

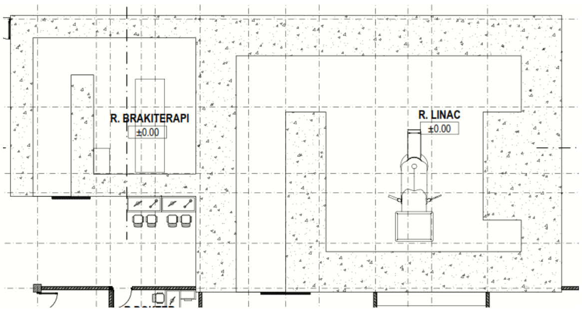


Figure 2. Layout of the LINAC and Brachytherapy Bunker

Scope and Limitations

Problem delimitation is a process of clearly and systematically defining the boundaries of the research problem, allowing the researcher to distinguish between the factors that are relevant and those that fall outside the scope of the study (Mardiaman, 2024). This study focuses on the structural analysis of the LINAC and Brachytherapy bunker buildings at RSUD Raden Mattaher Jambi. The primary objective is to compare the design (DED) and actual field implementation (ABD) of the column and slab structures. The analysis focuses on the column and slab structures of the LINAC and Brachytherapy bunkers at RSUD Raden Mattaher Jambi. It is based on project documentation and follows Indonesian standards SNI 1727:2020 (loads), SNI 1726:2019 (earthquake design), and SNI 2847:2019 (concrete structures). Structural modeling is conducted using ETABS version 21.0.0.

2. LITERATUR REVIEW

Indonesia is located in a region with high seismic activity. Since the magnitude and timing of earthquakes cannot be predicted with certainty, building structures must be designed with sufficient ductility to accommodate inelastic deformations during strong seismic events. The hierarchy of structural element failure must be carefully planned to ensure maximum energy dissipation during such events (Naibaho et al., 2015). In today's modern era, the construction industry has seen numerous innovations in infrastructure in line with technological advancements. In Indonesia, concrete is a widely utilized material in construction. It plays a crucial role as a fundamental structural component, forming both superstructures and substructures (Permana et al., 2023). According to Vinakota (2006), a structure can be defined as an assembly of individual elements connected and arranged in such a way that the entire system remains stable and undergoes no significant deformation while meeting specific performance criteria. In other words, a structure is a system specifically designed to withstand forces or loads (Iman et al., 2024).

In civil engineering, several common types of structures are recognized, including trusses, columns, beams, portals, and slabs. These structural types are distinguished based on the direction of the load acting on the centroid of the cross-section, which is associated with the structure's neutral axis. Loads acting perpendicular to the neutral axis are referred to as shear forces, while those acting parallel are called axial forces. Truss structures are designed specifically to resist axial forces, which include both tensile and compressive loads (Iman et al., 2024).

HEAVYWEIGHT CONCRETE

Radiation shielding concrete (RSC), also known as heavyweight concrete, is a specialized type of concrete with a density exceeding 2600 kg/m^3, specifically formulated to attenuate ionizing radiation such as gamma rays (γ), X-rays, and neutrons. The attenuation of radiation is achieved through absorption and scattering processes, with the effectiveness strongly influenced by the concrete's unit weight (Badarloo et al., 2022). The higher the density, the greater the linear attenuation coefficient (μ). Several studies have shown that concrete with a density ranging from 3012 to 3820 kg/m^3 achieves μ values between 0.224 and 0.265 cm^{-1}, indicating excellent radiation shielding performance. This type of concrete typically incorporates heavyweight aggregates such as barite, magnetite, hematite, steel scrap, or even depleted uranium to enhance its shielding capacity (Özen et al., 2016).

Column

A column is a vertical component of the structural framing system that functions to transfer loads from beams. As a compression member within a structure, the column plays a crucial role in maintaining the structural integrity of a building. Its primary function is to transmit all loads — including dead loads, live loads (such as occupants and furnishings), and lateral loads (such as wind) — down to the foundation. In reinforced concrete construction, there are three main types of columns: columns with lateral ties, columns with spiral reinforcement, and composite columns (Afnaldi et al., 2022).

All structural columns experience a combination of axial loads and bending moments, requiring careful design to resist both types of forces effectively. The material properties and dimensional parameters of rectangular and circular columns—such as compressive strength (fc'), yield strength (fy), width (b), depth (d), height (h), and ultimate moment (Mu)—are comparable to those used in flexural beam design, with certain specifications unique to circular columns. In many instances, columns are subjected to biaxial bending, meaning they bend along two orthogonal axes. This condition commonly occurs in corner columns of buildings, where beams and girders intersect the columns from perpendicular directions (Bagio et al., 2021).

Slab Structure

According to Pratomo and Hudori (2021), a slab is a horizontal structural element designed to support both dead and live loads, transferring them to the vertical components of the structural system. The primary function of the slab is to act as a diaphragm or horizontal bracing element, which significantly contributes to the rigidity of beam-column frames in building structures. Additionally, slabs are utilized to provide flat and even surfaces in concrete construction (Hutagalung et al., 2024).

According to Ali Asroni (2010), a slab is a thin structural element made of reinforced concrete, oriented horizontally and subjected to loads acting perpendicular to its surface. The thickness of the slab is relatively small compared to its span length or width. Due to its high rigidity and horizontal orientation, reinforced concrete slabs function as diaphragms or structural bracing elements in building structures (Nurfandi & Roesdiana, 2022).

Loading

Loading is a crucial factor in the design of building structures. To properly design a structure, it is necessary to identify the loads acting on it. The loads affecting a structure can generally be classified into three categories: dead loads, live loads, and environmental loads such as earthquake forces (Afnaldi et al., 2022).

3. RESEARCH METHODOLOGY

The subject of this research is the construction project of the Linac and Brachytherapy Bunker at Raden Mattaher Regional General Hospital (RSUD) in Jambi. The object of the study focuses on the structural work of the project, which involves structural analysis using ETABS software.

The data utilized in this study consist of the Detail Engineering Design (DED) and actual structural data obtained from the field. Structural modeling was carried out to analyze and compare the behavior of the building structure based on the planned design data (DED) and the as-built field data. The structural loading design was conducted in accordance with the applicable regulations and current standards (Naibaho et al., 2024). The column structure of the LINAC and Brachytherapy Bunker Building at Raden Mattaher Regional Hospital, Jambi, consists of four types of columns. All columns have square cross-sections. There is no difference in column cross-sectional dimensions and reinforcement between the Detail Engineering Design (DED) and the actual structure in the field :

Table 1. Column Types and Dimensions

Column Type	Column Dimensions (mm)	
	Height (h)	Width (b)
K1	1800	1800
K2	1800	1000
K3	1000	3500
K4	1000	1000

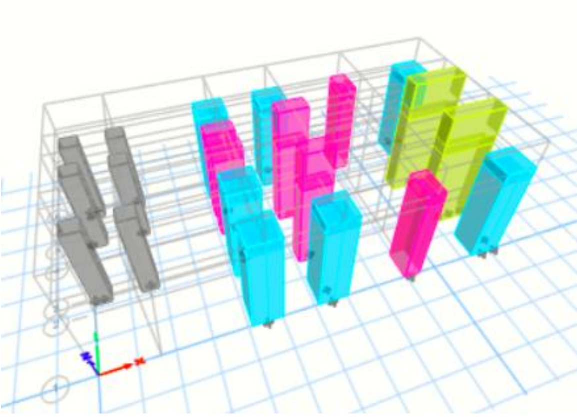


Figure 3. Column Modeling Results

The floor slab of the LINAC and Brachytherapy Bunker Building at Raden Mattaher Regional Hospital, Jambi, consists of three slab types. Each slab type has different thicknesses and reinforcement details. There is no difference in slab thickness between the Detail Engineering Design (DED) and the actual structure in the field; however, differences exist in the reinforcement details of each slab type between the DED and field data. The thicknesses of each slab type used in the LINAC and Brachytherapy Bunker Building at Raden Mattaher Regional Hospital, Jambi, are presented in the following table :

Table 2. Floor Slab Dimensions

Slab Type	Thickness (mm)
Slab D	1000
Slab E	1700
Slab F	3500

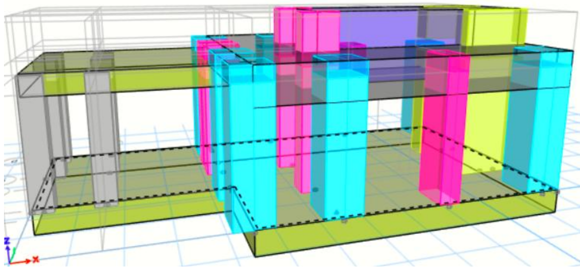


Figure 4. Floor Slab Modeling Results

The walls of the LINAC and Brachytherapy Bunker Building at Raden Mattaher Regional Hospital, Jambi, consist of three wall types. Each wall type has different thicknesses and reinforcement details. There is no difference in wall thickness between the Detail Engineering Design (DED) and the actual structure in the field; however, differences exist in the reinforcement details of each wall type between the DED and the field data. The thicknesses of each wall type used in the LINAC and Brachytherapy Bunker Building at Raden Mattaher Regional Hospital, Jambi, are presented in the following table :

Table 3. Wall Dimensions

Wall Type	Thickness (mm)
Wall A	1000
Wall B	1800
Wall C	3500

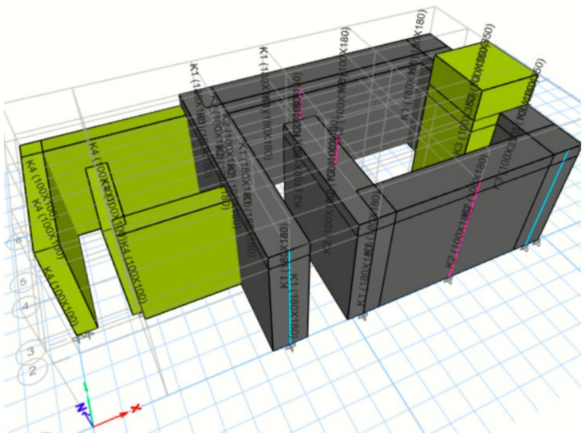


Figure 5. Wall Modeling Results

The beam structure of the LINAC and Brachytherapy Bunker Building at Raden Mattaher Regional Hospital, Jambi, consists of only one type of beam with a cross-sectional dimension of 600 × 1700 mm. This beam structure exists only in the actual field construction and is not included in the Detail Engineering Design (DED).

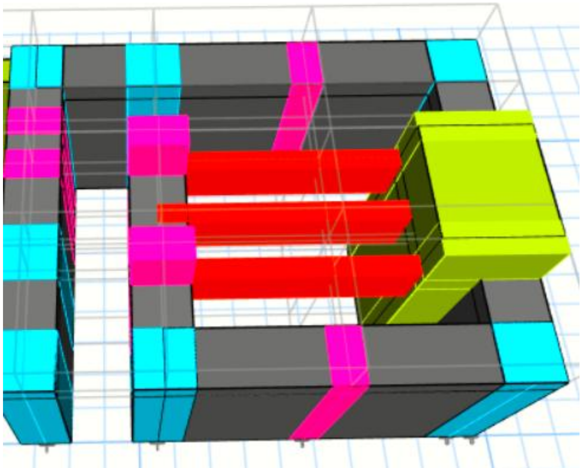


Figure 6. Beam Modeling Results

This study employs two types of modeling in its analysis: Model A, which is based on data from the Detail Engineering Design (DED), and Model B, which utilizes actual data obtained from field conditions. The DED data serves as secondary data sourced from planning documents, while the actual data is collected through direct observation at the project site. The following flowchart illustrates the stages of the research conducted.

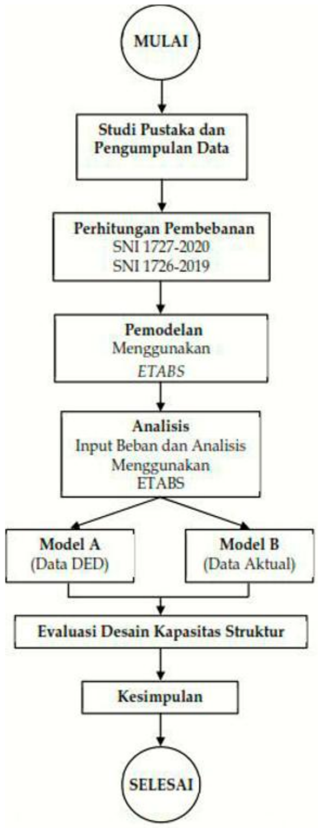


Figure 7. Research Flowchart

The self-weight of structural elements is automatically calculated by the ETABS software. Additional dead loads, live loads, rain loads, and wind loads are applied following the loading provisions of SNI 1727-2020. Seismic loads in ETABS are modeled dynamically by inputting response spectrum parameters obtained from the Indonesia Design Spectrum application 2021, which refers to the 2017 Seismic Source and Hazard Map and complies with SNI 1726-2019. Furthermore, the modeling in this study adheres to the Indonesian National Standard SNI 2847-2019 concerning Structural Concrete Requirements for Building Structures (Naibaho et al., 2024).

4. RESULTS AND DISCUSSION

Model A was developed based on drawings and data from the Detail Engineering Design (DED), whereas Model B was created using actual data obtained directly from the field (ABD). During the physical construction process, several design modifications occurred, including the addition of three beams measuring 600 x 1700 mm beneath slab type F, which were not originally included in the initial plan. Additionally, there were changes in the reinforcement installed on the bunker slab and walls, resulting in deviations from the DED data.

Structural Analysis of Column

In this study, the column elements were analyzed using ETABS software and consist of four different types. The variations in column types are due to differences in wall thickness and bunker height. To provide a detailed overview of the analysis method, a sample calculation is presented for one column type, namely K3 (1000x3500). This column was selected because it plays a significant role in the building's vertical frame system and features additional beam elements in the as-built condition that were not included in the original design. The material properties and cross-sectional dimensions of the K3 (1000x3500) column are presented in the following table :

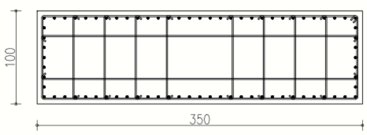
KODE	K3 (KOLOM 100x3500)
POSISI	-
POTONGAN	
DIMENSI	1000x3500
TULANGAN	76 D25
SENGKANG	D10 - 100

Figure 8. Detail Drawing of Column K3

Table 4. Properties of Column K3

Properties of Column K3	Value	Unit
Column length or height, L	8700	mm
Column short side, b	1000	mm
Column long side, h	3500	mm
Diameter of longitudinal reinforcement, d_b	25	mm
Diameter of transverse reinforcement, d_s	10	mm
Clear concrete cover, c_c	50	mm
Concrete compressive strength, f_c'	40,7	MPa
Yield strength of reinforcement, f_y	390	MPa
Beam height, h_b	1700	mm
Effective column length, $L_n = L - h_b$	5200	mm
Effective Depth, d	3450	mm

The properties of column K3, with dimensions of 1000x3500 mm, were input into the SPColumn software along with the internal forces obtained from the structural analysis using ETABS. This process produced the column interaction diagram as shown in the following figure

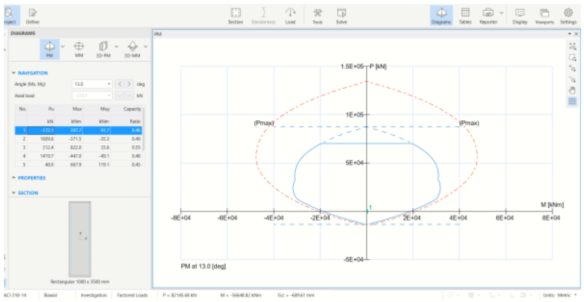


Figure 9. SPColumn Output Image of Column K3

Eccentricity due to moment (eo1)

$$eo1 = \frac{M}{P} = \frac{109187,5}{273730,34} = 39,89\ cm$$

Eccentricity due to section height

$$eo2 = \frac{1}{30} \cdot h = \frac{1}{30} .350 = 11,67\ cm$$

Total eccentricity

$$eo = eo1 + eo2 = 51,56\ cm$$

$$\frac{eo}{ht} = \frac{51,56}{350} = 0,15 \text{ cm}$$

Other calculations

$C2$ = 7,14

$C1$ = 1 (1 for rectangular columns, 1,15 for circular columns)

Calculation of secondary eccentricity

$$e1 = C1 \cdot C2 \cdot \left(\frac{lk}{100 \cdot ht}\right)^2 \cdot h$$

$$e1 = 1 \cdot 7{,}14 \cdot \left(\frac{520}{100 \cdot 350}\right)^2 \cdot 350$$
$$e1 = 0{,}552 \text{ cm}$$

Additional eccentricity
$$e2 = 0{,}15 \cdot h = 0{,}15 \cdot 350 = 52{,}5 \text{ cm}$$

Total Eccentricity
$$e_u = e_o + e_1 + e_2 = 104{,}61\ cm$$

Final Eccentricity
$$eau = eu + \left(\frac{1}{2} \cdot h\right) = 279{,}61 \text{ cm}$$

The resulting moment due to the axial force and eccentricity is:
$$P \cdot eau = -273730{,}34 \text{ x } 279{,}61$$
$$P \cdot eau = -76537001{,}71 \text{ kg.cm}$$
$$P \cdot eau = -765370{,}02 \text{ kg.m}$$

Moment Ratio Calculation
$$m = \frac{fy}{0.85 \cdot fc'} = \frac{390}{0.85 \cdot 40{,}7} = 11{,}27$$

Nominal strength calculation
$$Rn = \frac{M}{(f \cdot b \cdot d^2)} = \frac{-7653700171}{0{,}85 \cdot 3500 \cdot (3450)^2} = -0{,}216$$

Reinforcement ratio calculation
$$\rho_{required} = \frac{1}{m} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot Rn \cdot m}{fy}}\right)$$
$$\rho_{required} = \frac{1}{11{,}27} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot -0{,}216 \cdot 11{,}27}{390}}\right)$$
$$\rho_{required} = 0{,}00055$$

In accordance with SNI 2847:2019, the longitudinal reinforcement area Ast must range between 1% and 6% of the gross section area Ag. Accordingly, the reinforcement ratio is selected within the allowable range of 1% <= ρ <= 6%.

The provided reinforcement consists of 76 D-25 bars with a total area of 37.288 mm^2.
$$\rho_{actual} = \frac{As}{b.h} = \frac{37.288}{1000.3500} = 0{,}0107$$
$$\rho_{actual} = 1{,}07\ \%\ [OK]$$

The structural analysis results for column K3 indicate that the column meets the required strength criteria. This is evidenced by the actual reinforcement ratio (ρ_{actual}) of 1.07%, which is higher than the required minimum reinforcement ratio ($\rho_{required}$). Additionally, the longitudinal reinforcement ratio falls within the allowable range specified by SNI 2847, namely between 1% and 6%. Therefore, it can be concluded that the column has sufficient capacity to withstand the applied loads, even with an adequate strength reserve. The following table presents the analysis results of the column calculations for the bunker structure:

Table 5 Results of Column Analysis

Coloumn	**K1**		**K2**	
Model	**DED**	**ABD**	**DED**	**ABD**
P max (kN)	925,8	1229	-50,7	-71,6
P min (kN)	-2360	-2378	-2695	-823,2
M max (kN.m)	421,4	487,6	556	176,4
M min (kN.m)	-561,6	-555	-558	-172,1
ρ	1,03%		1,04%	

Coloumn	**K3**		**K4**	
Model	**DED**	**ABD**	**DED**	**ABD**
P max (kN)	683,1	270,3	103,9	128,5
P min (kN)	-2068	-2685	-719,7	-736,5
M max (kN.m)	1182,6	1071,1	25,8	29,1
M min (kN.m)	-651,4	-730,5	-29,9	-32,3
ρ	1,07%		1,3%	

Structural Analysis Floor Slab

In this study, three types of floor slabs were analyzed as structural elements. A sample calculation is presented for one slab type, namely Slab F. The flexural reinforcement analysis was carried out assuming a unit width of one meter along the span. The reinforcement calculations were conducted based on the two principal directions of the slab, namely the X-axis and Y-axis.

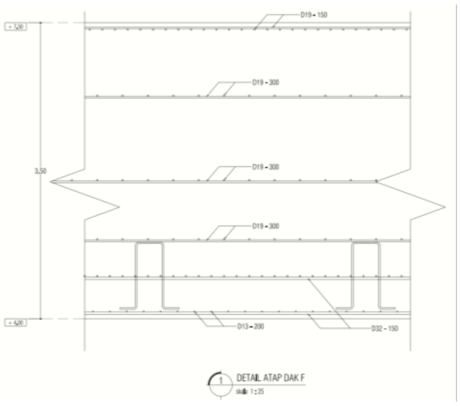


Figure 10. Detail Drawing of Floor Slab F

Table 6. Properties of Slab F

Properties of Slab F	Value	Unit
Slab Length in Direction 1, $L1$	12300	mm
Slab Length in Direction 2, $L2$	4800	mm
Slab Thickness, t	3500	mm
Diameter of reinforcement, d_b	13; 19; 32	mm
Clear concrete cover, c_c	25	mm
Concrete compressive strength, f_c'	40,7	MPa
Yield strength of reinforcement, f_y	390	MPa
Modulus of Elasticity of Concrete, Ec	29984	
β1	0,7593	
λ	1	
Minimum Reinforcement Area, As min (fy < 420 MPa)	7000	mm²

Slab Reinforcement

According to SNI 2847:2019 for $28 < f_c' > 55$ MPa.

$$\beta_1 = 0{,}85 - 0{,}05\left(\frac{f_c' - 28}{7}\right) = 0{,}7593$$

Based on SNI 2847:2019 for non-prestressed solid slabs, the maximum spacing of longitudinal reinforcement (S_{max}) must be the lesser of twice the slab thickness (2t) or 450 mm.

$$s_{max} = 2t = 2(3500) = 7000\ mm$$

It can be observed that the installed reinforcement spacing is less than the allowable maximum spacing S_{max} = 450 mm mm, thus meeting the requirements of SNI 2847:2019.

Bottom midspan reinforcement

Based on the As Built Drawing (ABD), the midspan flexural reinforcement consists of two layers with total installed reinforcement area in x direction:

$$A_s installed = 11259{,}468\ mm^2$$

Effective depth considering two layers:

$$d = 3225\ mm^2$$

Depth of equivalent stress block:

$$a = \frac{A_s.fy}{0{,}85.f'c.b} = \frac{11259{,}468.390}{0{,}85.40{,}7.1000} = 126{,}931\ \text{mm}$$

Nominal moment capacity:

$$Mn = A_s.fy.\left(d - \frac{a}{2}\right) = 13882{,}906\ kN.m$$

Neutral axis depth:

$$c = \frac{a}{\beta_1} = \frac{126{,}931}{0{,}7593} = 167{,}172\ \text{mm}$$

Tensile reinforcement strain:

$$\varepsilon_s = \frac{d - c}{c.0{,}003} = \frac{3225 - 167{,}172}{167{,}172.0{,}003} = 0{,}055$$

Strength reduction factor: $\phi = 0{,}9$

Design moment capacity :

$$\phi.Mn = 0{,}9.13882{,}906 = 12494{,}615\ kN.m$$

Capacity check:

$$Mu = 3685{,}797\ \text{kN.m} < \phi.\text{Mn (OK)}$$

Top Support Reinforcement

According to the as-built drawing, the top support flexural reinforcement consists of four layers with total installed reinforcement area in x direction:

$$A_s installed = 4725{,}479\ mm^2$$

Effective depth considering three layers:

$$d = 2417{,}54\ mm^2$$

Depth of equivalent stress block:

$$a = \frac{A_s.fy}{0{,}85.f'c.b} = 53{,}272\ \text{mm}$$

Nominal moment capacity:

$$Mn = A_s.fy.\left(d - \frac{a}{2}\right) = 4406{,}285\ kN.m$$

Neutral axis depth:

$$c = \frac{a}{\beta_1} = 70{,}16\ \text{mm}$$

Tensile reinforcement strain:

$$\varepsilon_s = \frac{d-c}{c.0{,}003} = 0{,}1$$

Strength reduction factor: $\phi = 0{,}9$

Design moment capacity :

$\phi.Mn = 0{,}9.4406{,}285 = 3965{,}657\ kN.m$

Capacity check:

$Mu\ =\ 3685{,}797\ \mathrm{kN.m} < \phi.\mathrm{Mn}$ (OK)

Slab deflection control

Gross moment of inertia:

$I_g = \frac{1}{12}.b.h^3 = 3572916666666{,}67\ mm^4$

Cracking stress:

$f_r = 0{,}62\sqrt{f_c'} = 3{,}955\ MPa$

Neutral axis from top :

$y = \frac{t}{2} = 1750\ mm$

Cracking moment:

$M_{cr} = \frac{f_r.I_g}{y} = 8075{,}580\ kN.m$

Cracked moment of inertia:

$I_{cr} = 0{,}25.I_g = 893229166666{,}667\ mm^4$

From the ETABS analysis:

$M_a mid\ span = 887{,}327\ kN.m$

$M_a support = -2259{,}17\ kN.m$

$\frac{M_{cr}}{M_a} mid\ span = 9{,}101$

$\frac{M_{cr}}{M_a} support = 3{,}575$

Effective moment of inertia:

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 \times I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] \times I_{cr} \leq I_g$$

$I_e mid\ span = 3572916666666{,}67\ mm^4$

$I_e suport = 3572916666666{,}67\ mm^4$

$I_e average = 3572916666666{,}67\ mm^4$

Immediate deflection:

$$\delta_i = \frac{5}{48}\frac{L^2}{(E_c.I_g)}[M_{mid} + 0{,}2.M_{supp}]$$

$\delta_{i,DL} = 0{,}194\ mm$

$\delta_{i,SIDL} = 0{,}001\ mm$

$\delta_{i,LL} = 0{,}001\ mm$

According to SNI 2847:2019, the limit for live load immediate deflection is L/360.

Check :

$\delta_{i,LL} = 0{,}001\ mm < \frac{L}{360} = 34{,}167\ mm$

Long-term deflection factor:

$\lambda = \frac{2}{1+50.\rho} = 1{,}635$

Long-term deflection:

$\Delta_{LT} = (\delta_{i,DL} + \delta_{i,SIDL}).\lambda + \delta_{i,LL} = 0{,}321\ mm$

According to SNI 2847:2019, the long-term deflection limit is L/240 or L/480 = 51.25 mm.

$\Delta_{LT} = 0{,}321\ mm < \frac{L}{240} = 51{,}25\ mm$ (OK)

The following are the results of the floor slab analysis for the bunker, comparing the design data (DED) with the actual field data (ABD):

Table 7 Results of Floor Slab Analysis

Model	DED	ABD
Slab	**D**	
Mu (kN.m)	156,3	164,03
Bottom midspan reinforcement		
ϕMn (kN.m)	926	1724,4
Top Support Reinforcement		
ϕMn (kN.m)	1054,3	1464,9
Slab	**E**	
Mu (kN.m)	2098,1	1954,1
Bottom midspan reinforcement		
ϕMn (kN.m)	1932,7	3041,7
Top Support Reinforcement		
ϕMn (kN.m)	2044,2	2200,1
Slab	**F**	
Mu (kN.m)	4530,1	3685,8
Bottom midspan reinforcement		
ϕMn (kN.m)	4254,8	12494,6
Top Support Reinforcement		
ϕMn (kN.m)	10796	3965,7

5. CONCLUSION

Based on the results obtined in this study, the following conclusions can be drawn:

The structural calculation and analysis of the columns refer to SNI 1726:2019 and SNI 2847:2019. The evaluation results indicate that the columns of the LINAC and Brachytherapy bunker structures are capable of withstanding the axial loads and moments that occur during operational conditions. The column reinforcement design has been adjusted to meet structural safety and seismic resistance requirements. Differences in internal forces were observed between the design data (DED) and actual field data (ABD); however, the analysis shows that the reinforcement ratio remains within the specified limits, ranging from 1% to 6% of the gross concrete cross-sectional area (Ag).

The floor slab in the LINAC and Brachytherapy bunker structure underwent reinforcement design changes between the design data (DED) and the actual field data (ABD). The analysis results indicate that the floor slab in the design data (DED) was unable to resist the internal forces generated by the loading simulation (Mu > ϕ.Mn). In contrast, the analysis of the actual field data (ABD) shows changes in internal forces and an increase in the nominal section capacity, which exceeds the ultimate moment demand (Mu < ϕ.Mn).

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