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Research Paper

Value Engineering Review of Structural Planing of Elementary Education Buildings with Performance-Based Seismic Design Pushover Analysis

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ABSTRACT: *Indonesia, located in a seismically active region, has numerous multi-story buildings that are crucial for supporting economic and educational activities. This research aims to perform value engineering on the existing structural design of buildings to be more earthquake-resistant and cost-efficient. The focus of the study is on identifying the structural elements that consume the largest budget and evaluating the seismic performance of the structure using different design methods. The results of the study indicate that floor slabs, beams, and columns are the dominant structural elements in the budget. Pushover analysis using the FEMA 440EL procedure on the existing design shows the potential for soft-story vulnerability and post-elastic collapse without achieving a performance point. Redesign using the force-based seismic design method (SNI 1726:2019) increases the cost of beams by 24.74% and the cost of columns by 3.47%, while the design approach with pushover analysis using the FEMA 440EL procedure significantly reduces the cost of beams and columns, while still meeting the desired performance target (Immediate Occupancy). This research concludes that the application of design with the pushover analysis approach using the FEMA 440EL procedure can be an effective solution for designing earthquake-resistant buildings with more efficient costs, reducing the cost of beams by 30.98% and columns by 27.86%..*

KEYWORDS: *Value Engineering, Pushover Analysis FEMA 440ELStructural Design Educational Buildings*

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I. INTRODUCTION

Indonesia is one of the countries located in the Pacific fire ring region, which makes it prone to earthquakes. Buildings with 1 (one) to 8 (eight) floors are buildings that dominate buildings in major cities in Indonesia, especially the city of Jakarta. Therefore, planning earthquake-resistant building structures is very important to ensure the safety and comfort of its occupants in carrying out every activity, including economic and educational activities. As one of the supports of economic and educational activities, the construction sector plays an important role in accelerating economic growth and educational facilities.

The construction sector, especially the construction of buildings, can be utilized as much as possible and as effectively as possible if the selection of the type of building structure in The implementation of the construction uses the cost as optimally as possible. A building not only needs to meet technical requirements (technically possible), but also meet economically feasible [1]. Through the creative hands of engineers, a construction or investment company can see potential savings in the project at hand. Although the success rate and savings value are different, it can be ensured that each project has the potential to save on existing design and/or savings on construction methods [2]. One of the management techniques in planning that is developing rapidly is value engineering which is a systematic approach and directed effort to analyze functions and costs of a project work in order to obtain optimal costs, with functional limitations and quality of work [3] By utilizing value engineering, savings can be made from the total project cost [4]. In recent years, the latest concept in building planning and evaluation for earthquakes is Performance Based Earthquake Engineering (PBEE) [5]. Performance Based Earthquake Engineering approach or commonly called Performance-Based Seismic Design (PBSD) This considers the performance of the structure in the form of an analysis of the level of collapse or the level of performance achieved by the structure at the time of an earthquake load [6]. The application of PBSD in the structural planning of primary and secondary education buildings can increase the efficiency and reliability of structures against earthquake loads. One of the approaches used to model the seismic performance of structures is Static Non-Linear Pushover Analysis FEMA 440EL Procedure, which allows for more detailed calculations of the capacity of structures, especially in terms of how structures behave under more extreme post-elastic seismic loads. Structural performance based on FEMA 273 related to the Operational performance level, immediate occupancy, life safety elevl, collapse prevention [7], [8], [9], [10] are described in Table 1.

Table 1. Structural Performance Levels Based on FEMA 273/356

No.	Performance Level	Description
1.	**Operational Level** (Operational Level)	Utility equipment is still functioning; there is little damage
2.	**Immadiate Occupancy Level** (Medium Usage Rate)	The building is safe to use from the inspection results; Needs a little improvement
3.	**Life Safety Level** (Safe to Habit Level)	The structure remains stable and has sufficient service capacity; Damage to non-structural parts is still under control
4.	**Collapse Prevention** (Collapse Prevention Rate)	The building remained standing, almost collapsed; other damages or losses are still allowed

Source: FEMA 273/356

The performance of the structure is based on ATC-40 which limits the maximum value of the interstorey drift limit to explain the relationship between each level of performance, be it Immadiate Occupancy, damage control, life safety and structural stability presented in Table 2.

Table 2. Drift limit ratio at performance level based on ATC-40

Performance Level				
Interstorey Drift Limit (Inter-Floor Intersection Limit)	**Immadiate Occupancy**	**Damage Control**	**Life Safety**	**Structural Stability**
Maximum Total Drift (Maximum Total Deviation)	0.01	0.01-0.02	0.02	$0.33\frac{V_i}{P_i}$
Maximum Inelastic Drift (Maximum Inelastic Deviation)	0.005	0.005-0.015	No Limit	No Limit

Source : ATC-40

The structural design approach in the review of the existing DED design using the Performance Based Seismic Design approach with the Static Non-Linear Pushover Analysis (Capacity Spectrum Method FEMA 440-EL) analysis method is carried out by being given lateral displacement to a certain limit with increments to show the collapse behavior of the structural system. From the results of the pushover analysis, it can be obtained that the Capacity Curve, Spectra Demand and Elastic Response Spectrum graphs are transformed into the Acceleration-Displacement Response Spectra (ADRS) format in ATC-40 (1996) and the ADRS curve is reduced to the Modified Acceleration-Displacement Response Spectra (MADRS) curve. [11] in FEMA-EL (Procedure C FEMA 440 EL in 2005 to determine the performance point of the structural system. The following is a schematic overview of the differences between the ADRS Curve Procedure in ATC-40 (1996) the Capability Spectrum Method (CSM) and the MADRS Curve in FEMA 440-EL The Capability Spectrum Method (CSM) has been updated to Equivalent Linearization Procedure (ELP). Explanation of the CSM Procedure curve in ATC-40 1996 explained Figure 1.

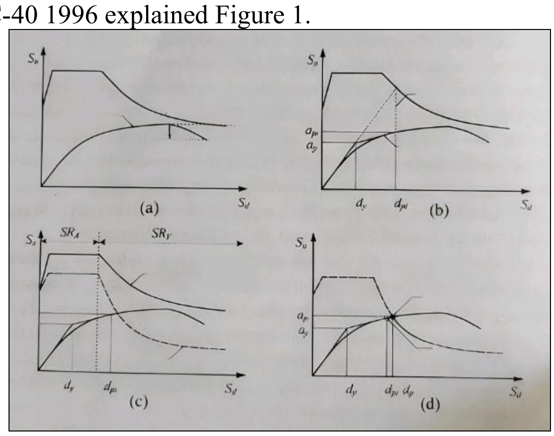


Figure 1. Stages of the CSM procedure in ATC-40 1996

Explanation of the 2005 FEMA 440EL procedure curve that is reduced from the ADRS curve to the MADRS curve is seen in Figure 2.

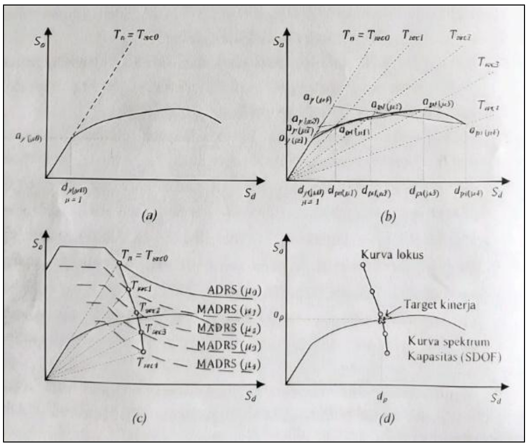


Figure 2. ELP procedure stages in FEMA 440EL 2005

II. RISEARCH OBJECTIVE

Based on the research background, the problems studied in this study include Knowing the types of structural work elements that spend the most project cost budgets. To determine the seismic performance of the existing DED structure, the DED Structure Review uses the SNI 1726:2019 Earthquake standard (Force-Based Seismic Design) and the DED Structural Review of the performance-based seismic design approach (Pushover-FEMA 440EL Analysis). Knowing the amount of DED costs for existing structures, the cost of DED review of structures using the SNI 1726:2019 Earthquake standard (Force-Based Seismic Design) and the cost of reviewing DED structures using a performance-based seismic design approach (Pushover-FEMA 440EL Analysis).

III. RESEARCH SCOPE

The scope of this study includes remodeling existing structures in the form of three-dimensional (3D) models to conduct modal analysis, so that structural dynamics in the form of shape modes with a cumulative mass participation ratio of at least 90% are obtained according to the provisions of SNI 1726:2019 [12]. The variety of fundamental vibrations of the structure is ensured to translate predominantly in the x-direction and y-direction to determine the period of the natural vibration of the structural fundamentals. Structural analysis of earthquake loads was carried out using two approaches, namely Strength-Based Design Earthquake-based linear analysis (Elastic) and nonlinear analysis based on Performance-Based Seismic Design through Pushover Analysis with Capacity Spectrum Method FEMA 440-EL. Structural comparative analysis was carried out for areas with high seismic rates, with a study location in DKI Jakarta Province, in order to evaluate the effectiveness of the application of Value Engineering in increasing the efficiency of the amount of reinforcement in the structural planning review while still meeting the required seismic performance criteria.

IV. RESEARCH METHODOLOGI

Value Engineering (VE) analysis is carried out in eight stages, namely the information stage, function analysis stage, creative stage, idea evaluation stage, idea development stage, alternative evaluation stage, recommendation feeding stage and presentation stage. The stages are as follows:

1. **Information Stage**
   At this information stage, efforts are made to obtain as much relevant information as possible.
2. **Function Analysis Stage**
   The function analysis stage is one of the stages of the value engineering work plan which aims to understand the project from the point of view of function based on what must be done. The initial stage of this analysis was carried out with the Functional Analysis System Technique (FAST) Diagram.
3. **Creative Stage**
   In Value Engineering, creative thinking is very important in developing ideas to come up with alternative-lateral elements that still fulfill the function, then arranged systematically.
4. **Idea Evaluation Stage**
   The purpose of the idea evaluation stage is to evaluate ideas that have the potential to provide added value.

5. Idea Development Stage
The idea development stage aims to develop ideas that have been evaluated from the idea evaluation stage to alternative.

6. Alternative Evaluation Stage
The alternative evaluation stage aims to find added value from the alternatives resulting from the idea development stage.

7. Recommendation Preparation Stage
The recommendation preparation stage aims to compile recommendations to be taken. By applying this principle, it can produce the best recommended solutions in the VE output process

8. Presentation Stage
This stage is the last stage in the VE work plan by collecting all the results from the information stage, function analysis stage, creative stage, idea evaluation stage, idea development stage, alternative evaluation stage, and recommendation feeding stage. At this stage of presentation, the author tries to convey that with the non-linear pushover static structure analysis approach , it will be obtained that the main structural elements are still possible to save the amount of reinforcement in earthquake-prone areas such as DKI Jakarta Province. The research steps carried out can be seen in the flowchart in Figure 3.

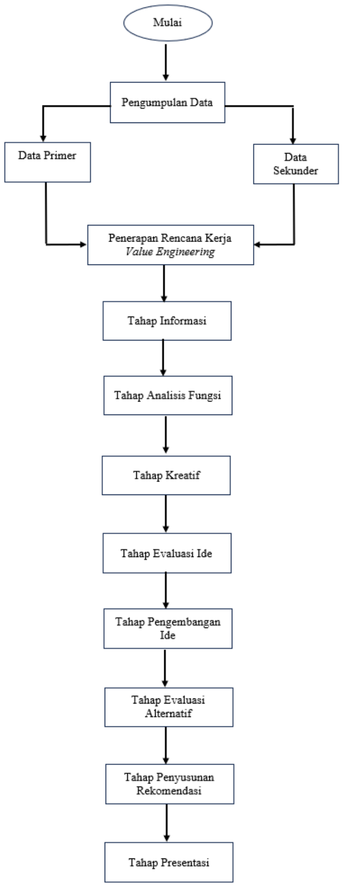


Figure 3. Research flowchart

V. RESULTS AND DISCUSSION OF THE RESEARCH

1.1. Information Stage

The building analyzed is a 6-storey building with the following data:

- Building Name : Elementary and Menenegah School Building
- Location: Central Jakarta
- Building Function : Educational Facilities
- Building Length : 20,625 m
- Building Width : 10.4 m
- Number of Floors : 6 Floors
- Height per Floor : 3.45m

- Total Building Height : 20.7 m

Concrete Material Data:

- Compressive Strength of Concrete (fc') = 24.90 MPa
- Specific Gravity =2400kg/m3
- Mod. Concrete Elasticity =23500 Mpa

Material Data of Reinforcement Steel:

- BJTS 420 fy = 420 Mpa
- Specific Gravity =7850 kg/m3
- Mod. Low Elasticity=200000Mpa
- Melting Strength (fy) = 420 Mpa
- Tensile Strength (fu) = 525 Mpa

Dimension of Structural Elements:

Table 3. Dimensions of Structural Elements

No.	Structural Elements	Remarks
1	Columns	K1 500x600, K1a.600x700, K1a. 700x800,
2	Beam	B1 300x600, B2 250x450, B3 350x650,
3	Floor Plates	t = 130 mm,
4	Ladder Plate	t = 150 mm,

Source : existing DED data

Table 4. Total cost of work

	Item Pekerjaan		Biaya	Presentase	Presentase Kumulatif
A	PEKERJAAN STRUKTUR	Rp	27.330.047.941	43,45%	43,45%
B	PEKERJAAN ARSITEKTUR	Rp	21.411.828.035	34,04%	77,49%
C	PEKERJAAN MEP	Rp	10.896.726.924	17,32%	94,82%
D	PEKERJAAN SITE DEVELOPMI	Rp	2.422.904.072	3,85%	98,67%
E	PEKERJAAN PERSIAPAN	Rp	835.638.254	1,33%	100,00%
	Biaya Total Konstruksi	**Rp**	**62.897.145.227**	**100,00%**	

Source: existing DED data

Building Structure Model:

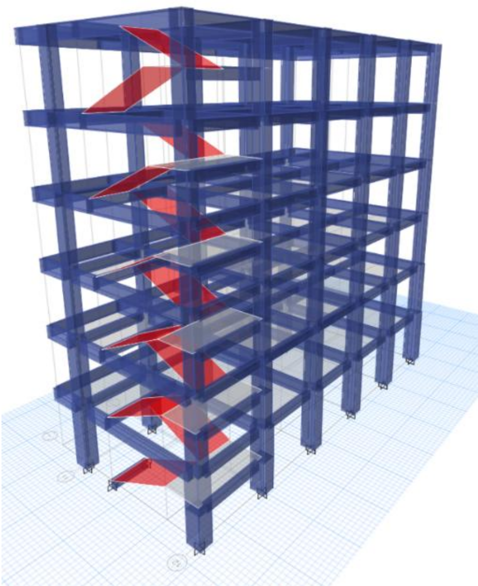


Figure 4. 3D Drawing of the structure

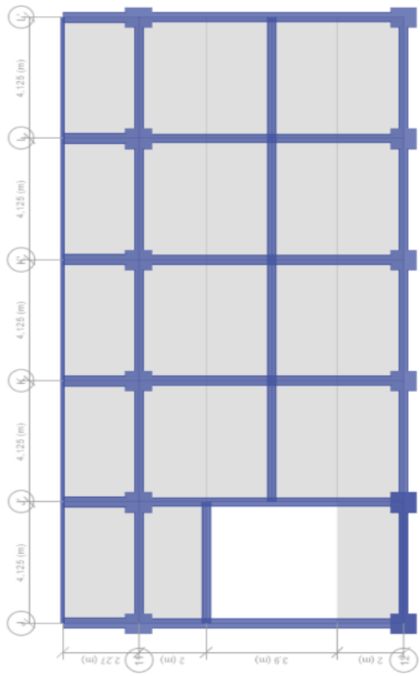


Figure 5. Structure Plan Drawing

Table 4. Cost Structure Work Model

No	Daftar Pekerjaan Struktur		Biaya		Kumulatif Biaya	Presentase	Presentase Kumulatif
1	Pekerjaan Struktur Bawah	Rp	5.889.689.385	Rp	5.889.689.385	21,55%	21,55%
2	Pekerjaan Struktur Atas	Rp	21.440.358.556	Rp	27.330.047.941	78,45%	100,00%
	Jumlah	**Rp**	**27.330.047.941**			**100,00%**	

Source : existing DED data

Table 5. Cost Upper structure work modelSource : existing DED data

No	Daftar Pekerjaan Struktur Atas		Biaya		Kumulatif Biaya	Presentase	Presentase Kumulatif
1	pekerjaan pelat lantai	Rp	7.615.655.082	Rp	7.615.655.082	35,52%	35,52%
2	pekerjaan balok	Rp	5.809.404.269	Rp	13.425.059.351	27,10%	62,62%
3	pekerjaan kolom	Rp	4.815.963.393	Rp	18.241.022.744	22,46%	85,08%
4	pekerjaan tie beam	Rp	1.254.408.109	Rp	19.495.430.854	5,85%	90,93%
5	pekerjaan tangga	Rp	1.097.211.691	Rp	20.592.642.544	5,12%	96,05%
6	pekerjaan struktur gwt	Rp	454.212.911	Rp	21.046.855.455	2,12%	98,16%
7	pekerjaan anti rayap	Rp	187.153.878	Rp	21.234.009.333	0,87%	99,04%
8	pekerjaan pelat meja	Rp	131.357.846	Rp	21.365.367.179	0,61%	99,65%
9	pekerjaan separator beam	Rp	74.991.377	Rp	21.440.358.556	0,35%	100,00%
	Jumlah	**Rp**	**21.440.358.556**			**100,00%**	

Source: existing DED data

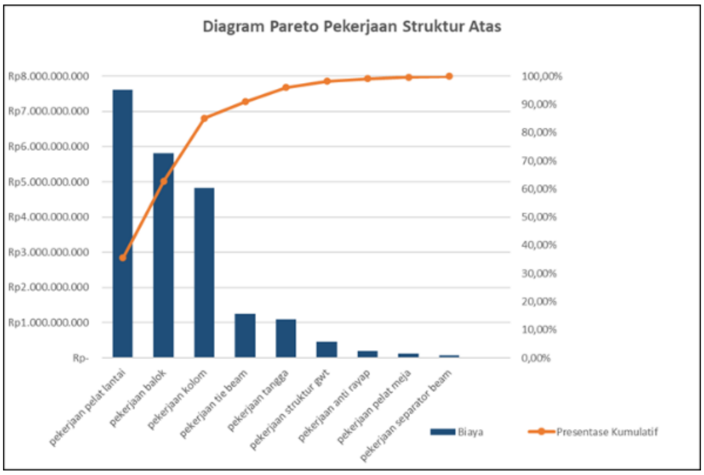


Figure 6. Pareto diagram of upper structure work

From the pareto results of the overall cost, it can be seen that in the upper structure work of the greatest weight is successively Work of the structure of the floor plate, the work of the beam structure and the work of the column structure with a value of 85.08% of the total cost of the work of the upper structure, but in accordance with the functional limitations, that the structural elements with the dominant function receive the lateral force of the earthquake directly with the target behaving dacttail in dissipating the energy of the earthquake is Beam and Column Work (beam structure elements and column structure elements) with a value of 49.56% of the entire cost of the upper structure work.

1.2. Function Analysis Stage

Function analysis is a fundamental stage in the study of Value Engineering which aims to identify and define the basic function and secondary function of each element or component of the work that is

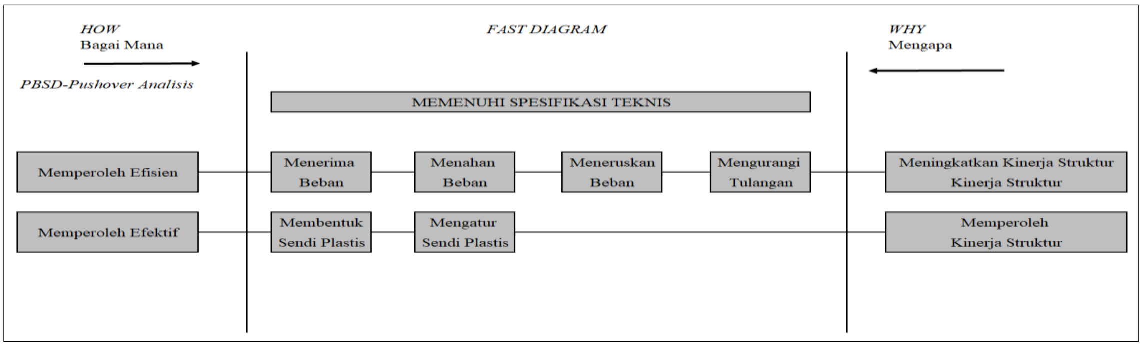


Figure 7. FAST Diagram

reviewed systematically, without first considering the technical solutions that are used. Function analysis is the main basis in value engineering because it is what distinguishes Value Engineering from other saving techniques. FAST (Function Analysis System Technique) is a method for analyzing, organizing and recording the functions of a system in a structured manner. Using this method, a diagram will be able to be built that describes the functions of each element in a project systematically and the relationship between each of them can be searched for functions and limitations of the scope of the problem being studied. The functions in the FAST diagram are identified by using verbs (verbs) and nouns (Nouns).

Table 6. Component function analysis

Kata Kerja	Kata Benda	Jenis Fungsi
Meningkatkan	Kinerja Stuktur	Primer
Memperoleh	Kinerja Stuktur	Primer
Memperoleh	Efisien	Primer
Memperoleh	Efektif	Primer
Menerima	Beban	Primer
Menahan	Beban	Primer
Meneruskan	Beban	Primer
Mengurangi	Tulangan	Primer
Membentuk	Sendi Plastis	Primer
Mengatur	Sendi Plastis	Primer

Source: Data processing

1.3. Creative Stage, Idea Evaluation Stage and Idea Development Stage

It is a stage of collecting alternatives as a review of the existing DED using brainstorming techniques that aim to achieve cost efficiency of structural work. The stages carried out are:

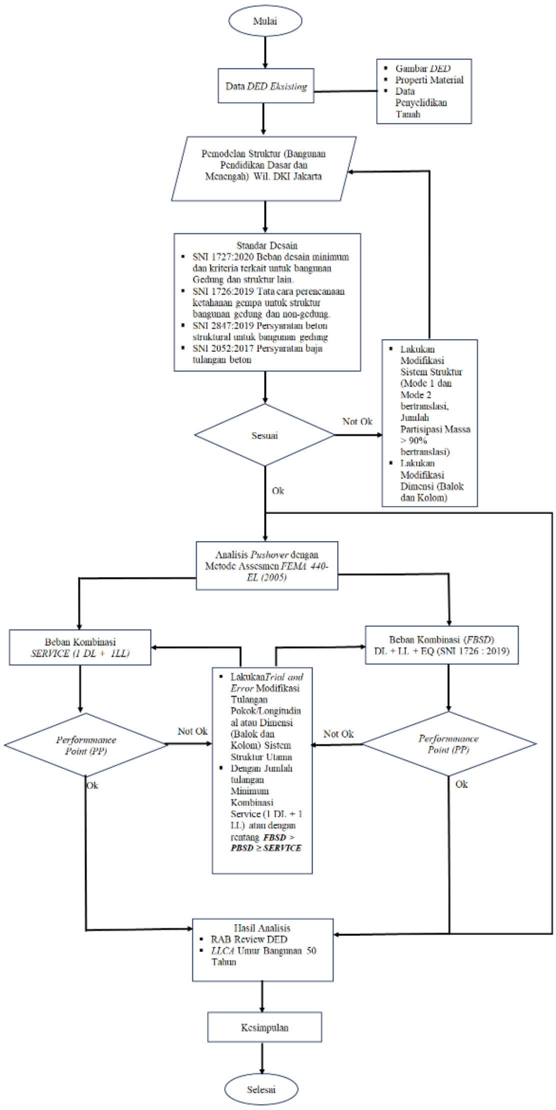
a. Conduct a review of DED of existing structures in accordance with SNI 1727:2020, SNI 1726:2019, and SNI 2847:2019 (Force-Based Seismic Design) [12], [13], [14], [15], [16].
b. Conduct a review of the DED of existing structures with analysis according to the standards on, SNI 2847:2019, SNI 1727:2020 and Pushover Analysis of FEMA 440EL procedures, to obtain performance points [12], [13], [14], [15], [16].
c. Calculate the cost of beam and column elements from the Force-Based and Performance-Based Seismic Design methods (FEMA 440EL procedure Pushover Analysis) to compare with the cost of existing DED [11]

The idea evaluation stage is an important stage in the Value Engineering methodology which aims to assess and filter alternatives at the creative stage to obtain the most significant savings/efficiency. In the review study of the structure of primary and secondary education buildings, evaluation and analysis are focused on components and items of structural work that allow for significant cost savings/efficiency. Alternative assessments are carried out in accordance with the Pareto Analysis, which is used to identify the cost of components and items of structural work that exert a significant cost effect on the total cost of the structure work, the results of the pareto analysis of components and items of structural work in accordance with Table 5 in the Evaluation Stage of this idea are selected components and items of beam and column work that have a weight of 49.558% against the cost of the work of the upper structure and 38.878% to the total cost of structural work that can be categorized as the main component to be analyzed at a later stage.

In the development of ideas, the DED of existing structures is analyzed and recalculated using the same method, namely with SNI 1727:2020 concerning minimum design load and related criteria for buildings and other structures, SNI 1726:2019 concerning earthquake resilience planning procedures for building and non-building structures. SNI 2847:2019 concerning Structural concrete requirements for building SNI 2052:2017 concerning concrete reinforcement steel requirements and FEMA 440 (Equivalent Linearization Method) 2005. The stage of idea development can be explained in the flowchart of Figure 8. From the flow chart of the development stages of the idea above, the results of analysis and calculation are obtained which are divided into the following steps:

a. Re-analysis of the existing DED is in accordance with the reference standards SNI 1727:2020, SNI 1726:2019 and SNI 2847:2019. The column dimensions from the 1st floor to the 6th floor are uniform with Uk. 500mm x 600mm, the dimensions of the main beam Uk. 300mm x 600mm for the Y-direction and the dimensions of the beam Uk. 250mm x 450mm for the X-direction. From the results of structural analysis on the columns of the 1st floor, there was an O/S which showed that the number of design reinforcement needed was quite large, so that the cross-section of the Uk column. 500mm x 600mm is not enough. In the column, 2nd floor it can also be seen that the ratio of reinforcement to cross-section is more than 3% which indicates that the reinforcement is quite tight, it can be seen from the results of the analysis that the shear force of the main beams is Uk. 300mm x 600 ultimate shear force exceeds the nominal shear capacity so that in the next analysis (review of existing DED) is carried out
modification of dimensions for the 1st floor column and 2nd floor column and the dimensions of the main beams with trial and error up to the nominal capacity (Mn, Vn and Nn) of the beam and column elements greater than the ultimate load either for the combination of SNI 1726:2019 earthquake load (Force Based Design Eearthquake) or the combination of Service Load (Comb. 1 DL + 1 LL)

Figure 8. Idea development stage flow chart



b. The review of the existing DED is in accordance with the reference standards SNI 1727:2020, SNI 1726:2019 and SNI 2847:2019. The review was conducted on the existing DED including enlarging the dimensions of the 1st and 2nd floor columns that failed to bend and enlarging the dimensions of the main blocks that failed to shear, both the Y-direction beam and the X-directional beam. The enlargement of the dimensions of columns and beams is carried out by trial and error until the ratio of column reinforcement for the 1st and 2nd floors is obtained with a range of 1% to 2.5% and the dimensions of the main beam until the nominal shear capacity is met and if necessary, it can also improve the quality of concrete. So it can be seen that in the columns of the 1st and 2nd floors there was an enlargement, which was originally uk. 300mm x 600mm in a row to UK.700mm x 800mm (1st floor) and UK. 600mm x 700mm (2nd floor). For the dimensions of the beam that were originally uk. 300mm x 600mm to UK. 350mm x 700mm and UK beams. 250mm x 450mm to UK. 250mm x 500mm.

c. The pushover analysis was carried out by trial and error with the range of the number of principal/longitudinal reinforcement of FBSD > PBSD ≥ Comb. Service (1 DL + 1 LL) to obtain performance points (PP) and the optimal number of principal/longitudinal reinforcement with the performance target of primary and secondary education buildings with risk category IV.

From the results of pushover analysis carried out by trial and error to obtain performance points with beam and column dimensions in accordance with the results of the DED Force Based Seismic Design (SNI 1726:2019) review analysis, it was found that the performance of the structure based on FEMA 440EL (2005) with the appropriate performance level based on the Performance Objectives Graph (FEMA 356 / ASCE41) and Drift Limit Ratio at Performance Level Based on ATC-40, it is obtained that the performance level of the structure is at the Immadiate Occupansy (IO) level with the Base Shear FBSD value (SNI 1726:2019) of the X and Y axis directions of 1103.10 kN and the Base Shear Pushover of the FEMA 440EL procedure at the direction of the X axis performance point obtained at 1512.424 kN, for the Y-axis direction the performance point was obtained at 1188.098 kN. Comparison of the cost of existing DED analysis and DED review can be seen in Table 7 and Table 8

1.4. Alternative Evaluation Stage, Recommendation and Presentation Stage

Table 7. Details of Cost of Beam Structure Elements in Existing DED and DED Review

NO.	URAIAN PEKERJAAN	*DED Eksisting* VOLUME	Satuan	Harga Satuan (RP)	Jumlah Total Harga (RP)
A.	**Pekerjaan Balok**				
1.	**Pekerjaan Balok Lt. 2**				
	Balok B1 Uk. 300mm x 600mm				
a.	Beton fc 25 Mpa	74,03	m3	1.301.619	96.352.374,78
b.	Pembesian	14.199,18	kg	15.609	221.634.284,55
	Balok B2 Uk. 250mm x 450mm				
a.	Beton fc 25 Mpa	65,23	m3	1.301.619	84.910.749,92
b.	Pembesian	12.961,32	kg	15.609	202.312.686,55
2.	**Pekerjaan Balok Lt. 3**				
	Balok B1 Uk. 300mm x 600mm				
a.	Beton fc 25 Mpa	72,03	m3	1.301.619	93.751.739,25
b.	Pembesian	13.800,29	kg	15.609	215.408.039,75
	Balok B2 Uk. 250mm x 450mm				
a.	Beton fc 25 Mpa	64,31	m3	1.301.619	83.702.684,43
b.	Pembesian	12.796,85	kg	15.609	199.745.359,56
3.	**Pekerjaan Balok Lt. 4**				
	Balok B1 Uk. 300mm x 600mm				
a.	Beton fc 25 Mpa	56,14	m3	1.301.619	73.067.783,74
b.	Pembesian	10.775,52	kg	15.609	168.194.629,92
	Balok B2 Uk. 250mm x 450mm				
a.	Beton fc 25 Mpa	49,19	m3	1.301.619	64.024.102,99
b.	Pembesian	9.797,34	kg	15.609	152.926.203,38
4.	**Pekerjaan Balok Lt. 5**				
	Balok B1 Uk. 300mm x 600mm				
a.	Beton fc 25 Mpa	46,94	m3	1.301.619	61.095.488,66
b.	Pembesian	8.992,67	kg	15.609	140.366.175,68
	Balok B2 Uk. 250mm x 450mm				
a.	Beton fc 25 Mpa	41,52	m3	1.301.619	54.037.135,41
b.	Pembesian	8.263,61	kg	15.609	128.986.228,98
5.	**Pekerjaan Balok Lt. 6**				
	Balok B1 Uk. 300mm x 600mm				
a.	Beton fc 25 Mpa	46,94	m3	1.301.619	61.095.488,66
b.	Pembesian	8.992,67	kg	15.609	140.366.175,68
	Balok B2 Uk. 250mm x 450mm				
a.	Beton fc 25 Mpa	41,09	m3	1.301.619	53.477.032,32
b.	Pembesian	8.263,61	kg	15.609	128.986.228,98
6.	**Pekerjaan Balok Dag**				
	Balok B1 Uk. 300mm x 600mm				
a.	Beton fc 25 Mpa	46,94	m3	1.301.619	61.095.488,66
b.	Pembesian	8.992,67	kg	15.609	140.366.175,68
	Balok B2 Uk. 250mm x 450mm				
a.	Beton fc 25 Mpa	45,27	m3	1.301.619	58.924.309,44
b.	Pembesian	8.979,64	kg	15.609	140.162.782,66
				Total Pekerjaan Balok	**2.824.989.349,65**

NO.	URAIAN PEKERJAAN	*Review DED (Force-Based Seismic Design)* VOLUME	Satuan	Harga Satuan (RP)	Jumlah Total Harga (RP)
A.	**Pekerjaan Balok**				
1.	**Pekerjaan Balok Lt. 2**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	93,56	m3	1.301.619	121.778.695,90
b.	Pembesian	25.028,82	kg	15.609	390.673.714,46
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	50,74	m3	1.301.619	66.041.694,38
b.	Pembesian	11.423,43	kg	15.609	178.307.812,12
2.	**Pekerjaan Balok Lt. 3**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	91,03	m3	1.301.619	118.491.781,55
b.	Pembesian	24.325,70	kg	15.609	379.698.741,95
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	50,02	m3	1.301.619	65.102.087,89
b.	Pembesian	11.278,47	kg	15.609	176.045.104,49
3.	**Pekerjaan Balok Lt. 4**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	70,95	m3	1.301.619	92.349.560,01
b.	Pembesian	18.993,97	kg	15.609	296.475.885,76
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	38,26	m3	1.301.619	49.796.524,55
b.	Pembesian	8.634,86	kg	15.609	134.781.150,93
4.	**Pekerjaan Balok Lt. 5**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	59,32	m3	1.301.619	77.217.909,28
b.	Pembesian	15.851,34	kg	15.609	247.422.799,90
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	32,29	m3	1.301.619	42.028.883,10
b.	Pembesian	7.283,11	kg	15.609	113.681.710,60
5.	**Pekerjaan Balok Lt. 6**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	59,32	m3	1.301.619	77.217.909,28
b.	Pembesian	15.851,34	kg	15.609	247.422.799,90
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	31,96	m3	1.301.619	41.593.247,36
b.	Pembesian	7.283,11	kg	15.609	113.681.710,60
6.	**Pekerjaan Balok Dag**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	59,32	m3	1.301.619	77.217.909,28
b.	Pembesian	15.851,34	kg	15.609	247.422.799,90
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	35,21	m3	1.301.619	45.830.018,45
b.	Pembesian	7.914,19	kg	15.609	123.532.139,99
				Total Pekerjaan Balok	**3.523.812.591,66**

NO.	URAIAN PEKERJAAN	*Review DED (Performance-Based Seismic Design)* VOLUME	Satuan	Harga Satuan (RP)	Jumlah Total Harga (RP)
A.	**Pekerjaan Balok**				
1.	**Pekerjaan Balok Lt. 2**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	93,56	m3	1.301.619	121.778.695,90
b.	Pembesian	8.282,85	kg	15.609	129.286.665,99
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	50,74	m3	1.301.619	66.041.694,38
b.	Pembesian	6.480,66	kg	15.609	101.156.343,28
2.	**Pekerjaan Balok Lt. 3**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	91,03	m3	1.301.619	118.491.781,55
b.	Pembesian	8.050,17	kg	15.609	125.654.689,86
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	50,02	m3	1.301.619	65.102.087,89
b.	Pembesian	6.398,42	kg	15.609	99.872.679,78
3.	**Pekerjaan Balok Lt. 4**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	70,95	m3	1.301.619	92.349.560,01
b.	Pembesian	6.285,72	kg	15.609	98.113.534,12
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	38,26	m3	1.301.619	49.796.524,55
b.	Pembesian	4.898,67	kg	15.609	76.463.101,69
4.	**Pekerjaan Balok Lt. 5**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	59,32	m3	1.301.619	77.217.909,28
b.	Pembesian	5.245,73	kg	15.609	81.880.269,15
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	32,29	m3	1.301.619	42.028.883,10
b.	Pembesian	4.131,80	kg	15.609	64.493.114,49
5.	**Pekerjaan Balok Lt. 6**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	59,32	m3	1.301.619	77.217.909,28
b.	Pembesian	5.245,73	kg	15.609	81.880.269,15
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	31,96	m3	1.301.619	41.593.247,36
b.	Pembesian	4.131,80	kg	15.609	64.493.114,49
6.	**Pekerjaan Balok Dag**				
	Balok B1 Uk. 350mm x 650mm				
a.	Beton fc 25 Mpa	59,32	m3	1.301.619	77.217.909,28
b.	Pembesian	5.245,73	kg	15.609	81.880.269,15
	Balok B2 Uk. 250mm x 350mm				
a.	Beton fc 25 Mpa	35,21	m3	1.301.619	45.830.018,45
b.	Pembesian	4.489,82	kg	15.609	70.081.391,33
				Total Pekerjaan Balok	**1.949.921.663,51**

Source : Data processing

Table 8. Cost Details of Column Structure Elements in Existing DED and DED Review

NO.	URAIAN PEKERJAAN	*DED Eksisting* VOLUME	Satuan	Harga Satuan (RP)	Jumlah Total Harga (RP)
B.	**Pekerjaan Kolom**				
1.	**Pekerjaan Kolom Lt. 1**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	87,48	m3	1.301.619	113.865.663,57
b.	Penulangan	32.145,36	kg	15.609	501.755.375,06
2.	**Pekerjaan Kolom Lt. 2**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	74,52	m3	1.301.619	96.996.676,37
b.	Penulangan	23.415,45	kg	15.609	365.490.595,20
3.	**Pekerjaan Kolom Lt. 3**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	25.606,62	kg	15.609	399.692.497,96
4.	**Pekerjaan Kolom Lt. 4**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	22.765,02	kg	15.609	355.338.078,67
5.	**Pekerjaan Kolom Lt. 5**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	25.606,62	kg	15.609	399.692.497,96
6.	**Pekerjaan Kolom Lt. 6**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	21.879,83	kg	15.609	341.521.196,22
7.	**Pekerjaan Kolom Lt. Dag**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	8,28	m3	1.301.619	10.777.408,49
b.	Penulangan	2.699,14	kg	15.609	42.130.789,08
				Total Pekerjaan Kolom	**3.004.470.075,57**

NO.	URAIAN PEKERJAAN	*Review DED (Force-Based Seismic Design)* VOLUME	Satuan	Harga Satuan (RP)	Jumlah Total Harga (RP)
B.	**Pekerjaan Kolom**				
1.	**Pekerjaan Kolom Lt. 1**				
	Kolom Uk. 700mm x 800mm				
a.	Beton fc 25 Mpa	163,30	m3	1.301.619	212.549.238,66
b.	Penulangan	40.181,70	kg	15.609	627.194.218,82
2.	**Pekerjaan Kolom Lt. 2**				
	Kolom Uk. 600mm x 700mm				
a.	Beton fc 25 Mpa	104,33	m3	1.301.619	135.795.346,92
b.	Penulangan	21.464,16	kg	15.609	335.033.045,60
3.	**Pekerjaan Kolom Lt. 3**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	23.472,73	kg	15.609	366.384.789,79
4.	**Pekerjaan Kolom Lt. 4**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	20.867,93	kg	15.609	325.726.572,11
5.	**Pekerjaan Kolom Lt. 5**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	23.472,73	kg	15.609	366.384.789,79
6.	**Pekerjaan Kolom Lt. 6**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	20.056,51	kg	15.609	313.061.096,54
7.	**Pekerjaan Kolom Lt. Dag**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	8,28	m3	1.301.619	10.777.408,49
b.	Penulangan	2.474,21	kg	15.609	38.619.889,99
				Total Pekerjaan Kolom	**3.108.735.693,72**

NO.	URAIAN PEKERJAAN	*Review DED (Performance-Based Seismic Design)* VOLUME	Satuan	Harga Satuan (RP)	Jumlah Total Harga (RP)
B.	**Pekerjaan Kolom**				
1.	**Pekerjaan Kolom Lt. 1**				
	Kolom Uk. 700mm x 800mm				
a.	Beton fc 25 Mpa	163,30	m3	1.301.619	212.549.238,66
b.	Penulangan	26.787,80	kg	15.609	418.129.479,21
2.	**Pekerjaan Kolom Lt. 2**				
	Kolom Uk. 600mm x 700mm				
a.	Beton fc 25 Mpa	104,33	m3	1.301.619	135.795.346,92
b.	Penulangan	15.610,30	kg	15.609	243.660.396,80
3.	**Pekerjaan Kolom Lt. 3**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	12.803,31	kg	15.609	199.846.248,98
4.	**Pekerjaan Kolom Lt. 4**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	11.382,51	kg	15.609	177.669.039,33
5.	**Pekerjaan Kolom Lt. 5**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	12.803,31	kg	15.609	199.846.248,98
6.	**Pekerjaan Kolom Lt. 6**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	72,45	m3	1.301.619	94.302.324,25
b.	Penulangan	10.939,91	kg	15.609	170.760.598,11
7.	**Pekerjaan Kolom Lt. Dag**				
	Kolom K1 Uk. 500mm x 600mm				
a.	Beton fc 25 Mpa	8,28	m3	1.301.619	10.777.408,49
b.	Penulangan	1.349,57	kg	15.609	21.065.394,54
				Total Pekerjaan Kolom	**2.167.308.697,02**

Source : Data processing

From Table 7 and Table 8, it can be seen that compared to the existing DED, the DED review with a force-based seismic design approach (SNI 1726:2019) on beam elements experienced a cost increase of 24.74% due to changes in dimensions and the amount of reinforcement (Rp 698,823,242), while the performance-based seismic design approach (pushover-FEMA 440EL analysis) experienced cost reduction of 30.98% (Rp 875,067,686) and it can also be seen that compared to the existing DED, the DED review with a force-based seismic design approach (SNI 1726:2019) on the column element experienced a cost increase of 3.47% due to changes in dimensions and the amount of reinforcement (Rp 104,265,618), while the performance-based seismic design approach (pushover-FEMA 440EL analysis experienced a cost reduction of 27.86% (Rp 837,161,378).

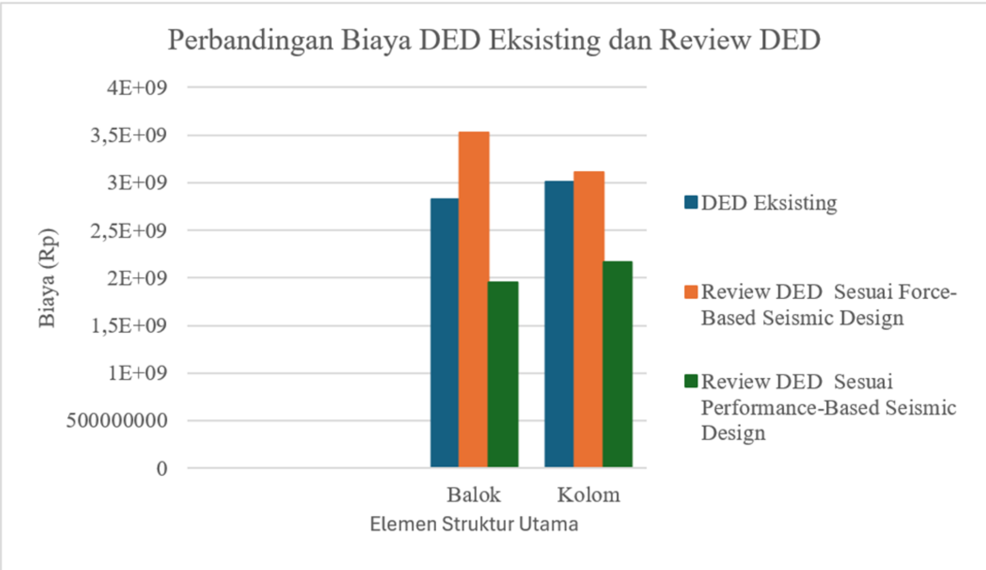


Figure 8. Cost Comparison Chart

II. RESEARCH CONCLUSIONS

Based on the Pareto Law test of the RAB of upper structure work, the largest consecutive costs are found in floor plates, beams, and columns with a total of 85.08% of the cost of the upper structure. However, the dominant structural elements of the direct earthquake force resistance, namely beams and columns, have a cost portion of 49.56% of the total cost of the upper structure. Pushover analysis of the FEMA 440EL procedure on the existing DED did not yield a Performance Point and showed an initial plasticization of the ground floor column causing soft storey in the post-elastic phase. On the other hand, in the review of DED based on force-based seismic design (SNI 1726:2019) and the DED review with a performance-based seismic design approach (Pushover-FEMA 440EL analysis), Performance Points were obtained with the occurrence of plasticization on the 2nd floor beam (SCWB met), which showed the behavior of the daktail with the Immediate Occupancy (IO) performance level. Compared to the existing DED, the force-based seismic design increased the cost of the beam by 24.74% (Rp 698,823,242) and columns by 3.47% (IDR 104,265,618), while the performance-based seismic design approach (Pushover-FEMA 440EL Analysis) reduced the cost of beams by 30.98% (IDR 875,067,686) and columns by 27.86% (IDR 837,161,378).

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