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An Overview of Commonly Used Steel Beam-Column Connection in Indonesia for Low-Rise Building

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***Abstract*—The Indonesian seismic provision for steel structures was initiated in 2002. Since then, the utilization of steel as a structural material has been on the rise. However, there have been numerous shortcomings in the seismic design of steel structures. Therefore, this article presents the results of a scientific review of the development of steel structures in Indonesia, both regarding the development of codes and their applications. In Indonesia, a significant number of steel buildings employ a haunch in their beam-column connections within a moment-resisting connection system. Haunched systems are not described in AISC 358 as permitted connections for earthquake-resistant buildings. Recently, Europe has published European Prequalified Steel Joints (EqualJoints). Four types of connections are discussed, and one of them is the haunched type connections. The haunched connection meets the seismic requirements to be suitable for use as an earthquake-resistant connection in Europe. This can be used as a reference if we are going to design a haunched connection in Indonesia. However, special attention should be paid to the details. The bolt configuration, the thickness of the end plates, and the shape of the haunch are not like those commonly used in Indonesia; there must be improvements to be adjusted in EqualJoints so that the performance of the connection against earthquakes becomes more guaranteed.**

***Keywords*—beam-column; connection; haunched; Indonesia; Europe; AISC 358; EqualJoints**

I. Introduction

Indonesia's position in the Ring of Fire causes most of its territory to be at high earthquake risk [1]. Most of the largest earthquakes that have ever existed in the world have occurred in Indonesia, Figure 1 illustrates the high potential for seismicity in Indonesia, 25% of severe earthquakes occurred in Indonesia. The General Insurance Rating Organization of Japan (2014) even states that the regions with the highest earthquake intensity are Japan, Indonesia, and New Zealand [2]. The high earthquake potential makes the tendency of research on steel structures always lead to earthquake resistance.

The development of research on steel and its application in Indonesia is not as advanced as in other developed countries [3]. While the recent codes are up to date, the research and application are still behind, especially in the area of seismic-resistant steel structures. There is a gap between steel structure research and its application in the field. Therefore, this article was created to provide a scientific review of Indonesia's current development of steel structures.

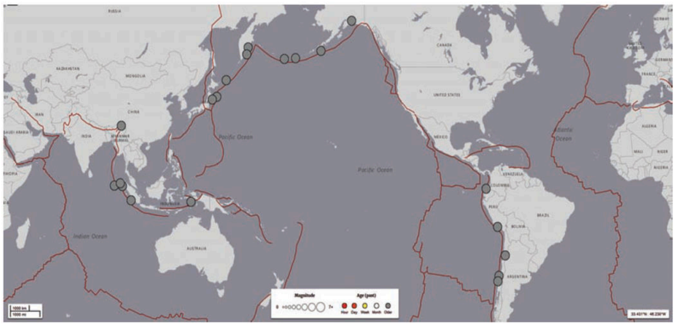

Figure 1. Records of the world's severe earthquake locations (1906-2011)
Source: https://earthquake.usgs.gov

Along with the increasing use of steel as the main structural material, seismic design still has many weaknesses. There are many inconsistencies with the current code, such as the selection of materials, the size of cross-section availability, and the connection systems [4].

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The connection system especially shown in Figure 2 is standard in low-rise steel building construction practices in Indonesia, namely the haunched systems, where seismic compliance is still questionable [4]. Many beam-column connections in steel buildings in Indonesia use a haunch in a moment-resisting connection system. Figure 3 also shows another connection system that is often used in Indonesia, which certainly requires further research where this connection system provides additional horizontal plates to connect the beam to the weak axis of the column.

Haunched systems are not described in [5,6] as permitted connections for earthquake-resistant buildings. In fact, it is widely used in the construction of steel structures. It can be said that this connection system is the most popular in Indonesia. The haunched system is a moment-resisting connection, similar to the prequalified connection, which is discussed in detail in AISC 358-16.

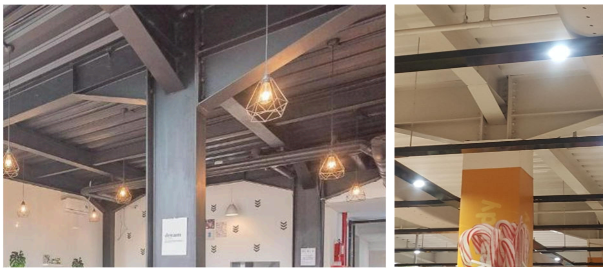


Figure 2. Moment resisting connection in two-axes
Source: Adapted from [4]

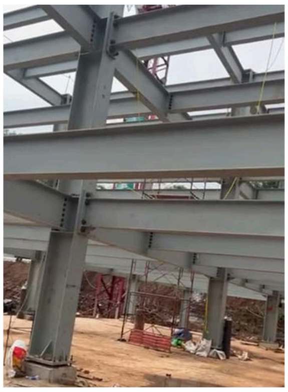


Figure 3. Connection with an additional horizontal plate to the weak axis of the column
Source: Adapted from [4]

In principle, the haunched connection system utilizes an end plate, where the connection system using an end plate has been proven to perform well in resisting earthquake loads [7,8]. Haunch beams are designed by assuming a rigid moment connection between the beam and column, therefore the size of the haunch is adjusted to be able to transfer the moment. The depth and length of the haunch are designed to reduce the depth of the beam in resisting the moment. Haunched connection design philosophy emphasizes strength, not ductility [9]. In addition, the connection must be stronger than the capacity of the beam so that the connection can transfer the applied moment when the beam reaches its ultimate capacity.

However, the use of prequalified connections, according to AISC 358-16/SNI 7972:2020 is not widely implemented in Indonesia. This may be due to the cost of manufacture, which will be expensive when compared to the haunched system. Meanwhile, from an implementation perspective, both prequalified and haunched moment connection systems have ease of fabrication and erection [10].

We can also compare the requirements in [5] with many connections in Indonesia, one of the differences lies in the position of the beam to the orientation of the column. The special moment frame connection requires the haunch to be connected to the column flange at the strong axis of the column. The performance of the moment-resisting frame connected to the column web at the weak axis of the column (Figures 2 and 3) is not clearly defined [11]. Further research is needed to anticipate the many inconsistencies in steel structural designs in Indonesia, especially earthquake-resistant connections.

This paper was compiled based on a literature review from related journals. The results are elaborated on the development of the steel industry, both in terms of code development, production, and application. The results of this study are expected to provide an overview to stakeholders to better understand the development of steel structures in Indonesia.

A. *Indonesian steel building codes*

Before 1990, there were limited structural steel buildings constructed in Indonesia as compared to reinforced concrete buildings [4]. Most of the steel buildings were one-story industrial buildings and were designed following the Indonesian Code for Steel Building Design (PPBBI-1984) [12] and Design Code for Structural Steel Buildings (SNI 1729-1989) [13]. Both of them had no specific provision for seismic-resistant steel buildings. The first Indonesian steel regulation that included seismicity provisions was SNI 1729-2002 [14].

SNI 1729 appeared in 2015 with significant changes. According to the adopted AISC, SNI is divided into 3 (three) parts, SNI 1729 [15] for the general design of steel, SNI 7860 [16] for seismic provision, and SNI 7972 [17] discusses prequalified connections for special and intermediate steel moment connections. The codes are then revised in 2021 to follow the latest AISC 2016 version. The current steel design codes in Indonesia have been considered up to date incorporating all steel seismic resistant structural systems; namely moment frames, braced frames, and shear-wall systems, the use of steel dampers to dissipate the seismic input energy to the building structures through the yielding of the steel dampers, as well as seismic isolation systems.

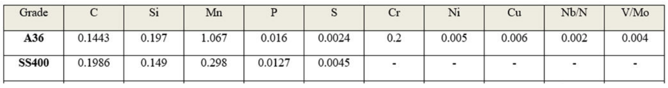
Based on developments in the Indonesian code, steel buildings that have been built for a long time will not meet the requirements, especially for seismic detailing. However, for new buildings, all aspects must be considered in order to create an earthquake-resistant building. Therefore, it is very important to update regularly the code that applies in a country.

B. *An overview of steel structures in Indonesia*

Apart from the connections as previously described, many things do not comply with the provisions of steel structures in Indonesia. The material types in SNI 1729:2020 are based on materials available in the U.S., while the sections in Indonesia mostly refer to Japanese regulations [18]. This is because Nippon Steel, Japan, in the 90s collaborated a lot with P.T. Krakatau Steel & Group. Since then, many Japanese standards or JIS (Japanese Industrial Standards) hot-rolled steel profiles have been produced and become a common profile. The problem is that there are many sizes of the JIS section, especially for the H-beam sections which do not meet the width-to-thickness ratio according to AISC 341-16 [18]. In fact, the slenderness requirements must be met to achieve high ductility.

Most industries in Indonesia do not use SNI, especially for hot-rolled sections [19]. Most of them use Japanese standards, for example using JIS G 3101 SS400 for hot rolled steel materials. While the plate uses ASTM A36 specifications. ASTM A36 and JIS G 3101 SS400 are the most widely produced materials. Based on information from P.T. Krakatau Posco [20], these materials have different chemical compositions and mechanical properties, as shown in Tables 1 and 2. Therefore, further analysis is needed to determine the structural behavior of different materials.

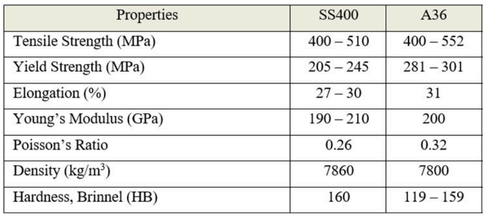
Table 1. Mild steel plate chemical composition



Grade	C	Si	Mn	P	S	Cr	Ni	Cu	Nb/N	V/Mo
A36	0.1443	0.197	1.067	0.016	0.0024	0.2	0.005	0.006	0.002	0.004
SS400	0.1986	0.149	0.298	0.0127	0.0045	-	-	-	-	-

Source: Adapted from [20]

Table 2. Mild steel plate mechanical properties



Properties	SS400	A36
Tensile Strength (MPa)	400 – 510	400 – 552
Yield Strength (MPa)	205 – 245	281 – 301
Elongation (%)	27 – 30	31
Young's Modulus (GPa)	190 – 210	200
Poisson's Ratio	0.26	0.32
Density (kg/m^3)	7860	7800
Hardness, Brinnel (HB)	160	119 – 159

Source: Adapted from [20]

Furthermore, the proper installation of bolts is crucial, as the tightening process must ensure that the connection meets the specified requirements [18]. In haunched connections, bolts play a key role as connectors. Therefore, specific guidelines exist for the technique of bolt tightening to ensure a rigid and expected behavior of the connection [21,22]. This objective can be accomplished by utilizing high-tensile bolts with pretension.

What about the application in Indonesia? No one can guarantee haunched connections using pre-tensioned bolts. What are the risks if only snug tights are installed? Need testing to prove it.

C. Performance of Haunched Connection System

The haunched moment connection has been used for a long time; the system refers to British Standard BS 5950: Part 1 [23]. The problem is that the haunched connection type is not explained in the SNI 7972:2020 Prequalified Connection Guide, which fully adopts AISC 358-16. The design concept of haunched joints according to BS 5950: Part 1 is explained in more detail in the manual SCI_P207, 1995 [24]. The design model used is based on the plastic strength distribution of the bolts.

Haunched connections typically use end plates that are approximately the same thickness as the beam flange [18]. Meanwhile, a prequalified connection according to SNI 7972:2020/AISC 358-16 will produce a large plate thickness and bolt diameter [25]. If the thickness of the plate does not meet requirements, a potential prying action will appear as shown in Figures 4 and 5 [25,26].

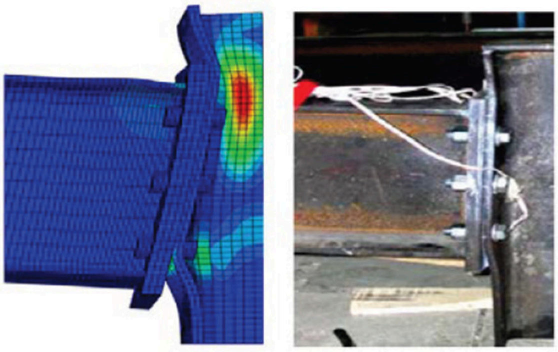


Figure 4. The failure mode of an end plate connection
Source: Adapted from [25]

The prying effect has become a weakness that must be avoided in the end plate connection system [27,28]. The prying action developed in the end plate can also cause a pinching phenomenon (Figure 9), as we can see in the hysteretic curve [29]. Meanwhile, haunched connections that are commonly used have not been tested for their performance against earthquake loads.

The configuration of bolts is arranged on the right and left sides along the height of the beam, with the vertical spacing between the bolts being the same or adjusted to the available space. The number of bolts is large with a small diameter. If it is assumed that the columns and beams are perfectly rigid and there is no deformation due to loading on the beam, then the beam will actually rotate about the lowest point of the beam. Due to the occurrence of strain on the bolt where the largest strain is on the top bolt, a gap is formed between the column and the beam, which forms a triangle, as shown in Figure 6. The axial tension of the bolt is proportional to its distance from the bottom flange of the beam.

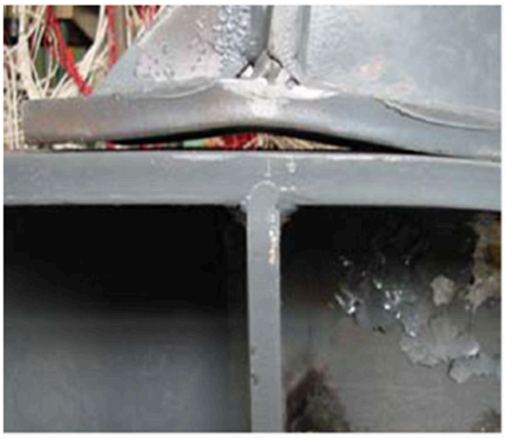


Figure 5. Prying action
Source: Adapted from [26]

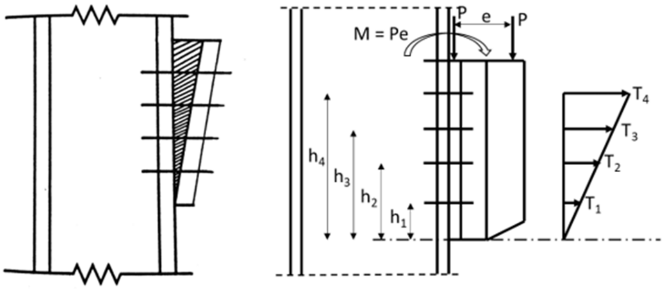


Figure 6. Connection mechanism
Source: Adapted from [24]

Based on the mechanism in Figure 6, it can be seen that in addition to bearing the tensile force due to the moment M, the bolts also bear the shear force P. The shear force P is carried by all the bolts equally. The top bolt carries a shear force of $T_4 = 0{,}5\ P/n$ (n = the number of bolts in one series). So one bolt carries a load of 0,5 P/4 = ⅛ P. So that each bolt carries a combined tensile and shear force of T_{max} and ⅛ P. To obtain the value of the tensile force for each bolt, the approximation method can be used, according to (1) to (6):

$$M = P \cdot e$$ (1) [24]

$$T_1 = T_4 \frac{h_1}{h_4}\,;\ T_2 = T_4 \frac{h_2}{h_4}\,;$$

$$T_3 = T_4 \frac{h_3}{h_4}\,;\ T_4 = T_4$$ (2) [24]

$$M = (T_1 h_1 + T_2 h_2 + T_3 h_3 + T_4 h_4) \cdot 2$$ (3) [24]

$$M = \left[T_4 \frac{h_1^2}{h_4} + T_4 \frac{h_2^2}{h_4} + T_4 \frac{h_3^2}{h_4} + T_4 \frac{h_4^2}{h_4}\right] \cdot 2$$ (4) [24]

$$M = 2T_4 \left[\frac{h_1^2 + h_2^2 + h_3^2 + h_4^2}{h_4}\right]$$ (5) [24]

$$T_4 = T_{max} = \frac{M \cdot h_4}{2 \cdot (h_1^2 + h_2^2 + h_3^2 + h_4^2)}$$ (6) [24]

$T_4 = T_{max}$ is the maximum tensile force

SCI_P60 determines that the length of the haunch ranges from 5% to 10% of the span of the beam. The best haunch height is as depth as the beam used. Thickness limits for each flange and web section of the haunch section, column flange plates, and end plates. The thickness of the end plates welded to the beam ranges from 20% to 30% thinner than the beam flanges. While the thickness of the column flange, SCI_P60 explains that the thickness should not be less than 80% of the thickness of the end plate. This provision [24] is commonly used as an initial reference when designing a haunched moment connection system. But that should be evaluated later.

Another thing that must be considered is the beam connection's position to the column orientation. The latest version of the seismic provisions [30] provides general guidelines to design the columns. However, no prequalified connection framing on the web of wide flange columns is available in [5]. On the other hand, brittle failure mechanisms (Figures 7 and 8) can affect the seismic performance of the structures if the biaxial effects are not considered, according to [29,31].

Many researchers have analyzed that problem. Lu. et al. [32] conducted an experimental study of weak-axis moment connections with I-beams and H-columns. The results showed a welding fracture at the conjunction of the diaphragm and beam-end flange (Figure 8). Experimental research on cyclic behavior in semi-rigid joints was performed by Shi et al. [29]. In their proposal, T-stubs connecting beams to the weak axis of the column were used. The results showed failure in beams and column web fractures (Figure 7).

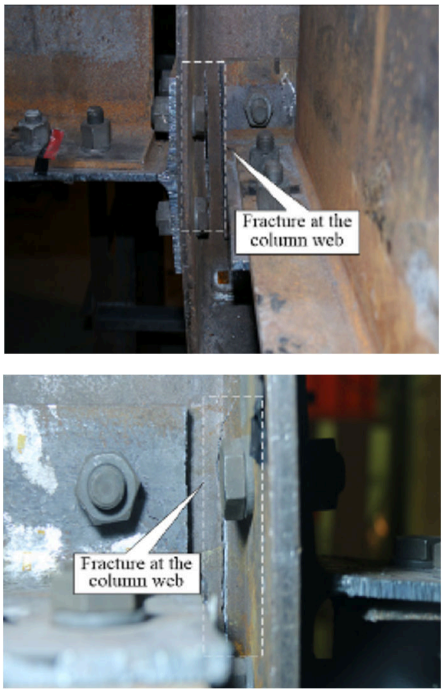


Figure 7. Fracture at column web (weak axis)
Source: Adapted from [29]

Based on the weaknesses in the haunched system as previously described, it is necessary to make improvements to the haunched connection design to avoid structural failure. Therefore further research is needed regarding the behavior of the haunched connections system in earthquake-prone areas is not in doubt.

D. Haunched Joint Behavior According to EqualJoint

Recently, Europe has published European Prequalified Steel Joints (EqualJoints) [33] because the current European code EN1993–1-8 [34] and EN1998–1 [35] do not provide easy-to-use design tools for steel beam-column connections [36]. In EqualJoint, there are four types of connections discussed, one of them is the haunched type connections, as shown in Figure 10. The joints are prequalified for typical multi-story buildings located in medium and high seismic areas and designed according to Eurocodes [36].

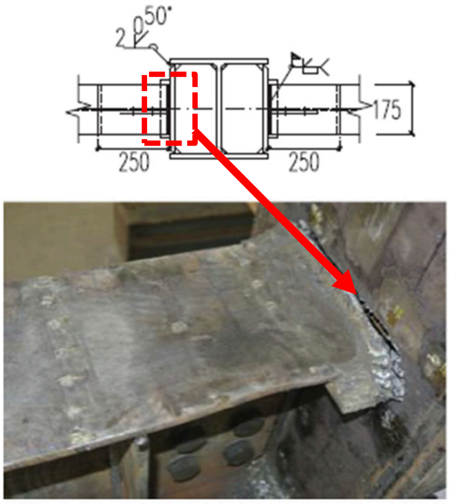


Figure 8. Brittle failure mechanism
Source: Adapted from [32]

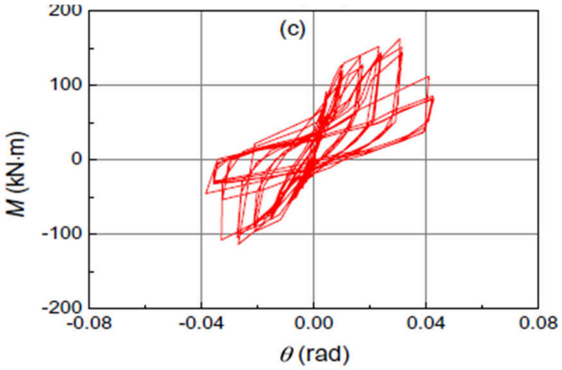


Figure 9. Decrease in rotational stiffness
Source: Adapted from [29]

Conceptually, this connection is similar to those widely applied in Indonesia. However, there are differences in bolt configuration and end plate thickness (Figure 11). It can be seen that the placement of the bolts in the EqualJoint is not evenly distributed as high as the cross-section, but the position of the bolts is adjusted only in the tension area [36]. Another thing, the thickness of the end plate is also much thicker compared to the Indonesia's haunched system.

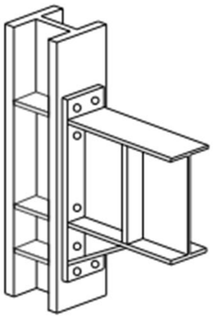


Figure 10. Bolted haunched joint
Source: Adapted from [36]

Based on the experimental tests (Figure 12) that have been carried out, the haunched connection meets the seismic requirements, so the haunched connection is suitable for use as an earthquake-resistant connection in Europe. How about Indonesia's haunched system? Better to prove it or directly adopt to Equaljoint.

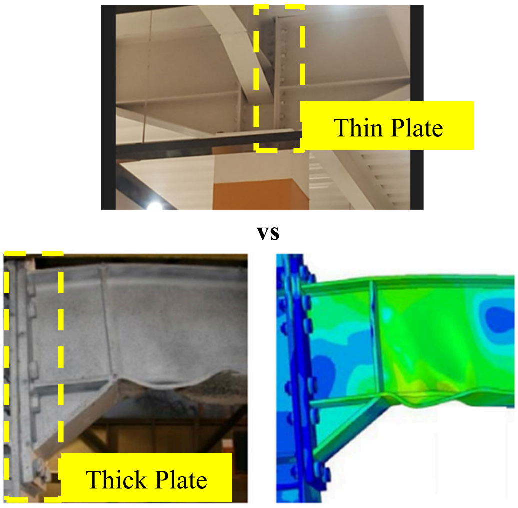


Figure 11. Differences in the configuration of Indonesia's haunched connections (top) and Equaljoint (bottom)
Source: Adapted from [36]

E. *Recommended Design Code*

Europe has provided a performance analysis of haunched-type joints [33]. Figure 12 shows a fat and stable hysteresis curve; it shows the great capacity of the structure to absorb energy. The deformation pattern

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shows that the damage occurs in the beam elements, not in the connection components, so the joints are suitable for use in areas with high seismic potential.

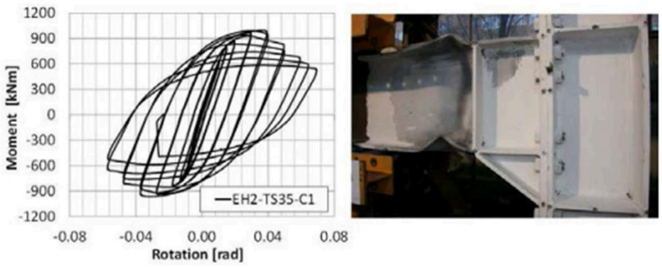

Figure 12. Moment-rotation behavior of haunched joint: plastic deformation occurring in the connected beam
Source: Adapted from [36]

This can be used as a reference if we are going to design a haunched connection in Indonesia. However, special attention should be paid to the details. The bolt configuration, the thickness of the end plates, and the shape of the haunch are not like those commonly used in Indonesia, there must be improvements to be adjusted as in EqualJoints so that the performance of the connection against earthquakes becomes more guaranteed.

II. Conclusion

Conclusions are written in this part.

1. In Indonesia, the design of steel structures exhibits variations in terms of materials, sections, and connection types employed.
2. Haunched connections are predominantly utilized for low-rise buildings in Indonesia, but their seismic structural performance remains untested.
3. EqualJoint offers an assessment of the seismic performance of haunched joints.
4. EqualJoints can serve as a valuable resource for designing haunched joints in Indonesia, but it is crucial to carefully consider the specific details involved.

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