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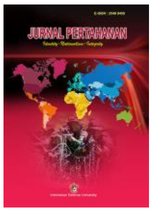

DISASTER RESILIENCE IN BUILDING CONSTRUCTION THROUGH CONCRETE CASTING METHODS: IMPLICATIONS FOR THE USE OF STRONG COLUMNS AND WEAK BEAMS

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Abstract

The difficulty in obtaining the construction of a strong-beam-weak column building will be encountered during the concrete casting work because in the implementation the beam may be cast using a higher quality concrete than that used for column casting. This has the potential to result in the construction of strong weak-beam columns which should be avoided in earthquake-resistant structures. This study aims to find the most effective concrete casting method that results in the construction of strong-weak beam-columns as intended above. Observations were made on the construction work of a four-story concrete construction building. Analysis by comparing all foundry works whose implementation uses ready mixed concrete made from one vendor, with those using different vendors for each casting of different building structural components. The data used are in the form of compressive strength test results for column casting samples and beam casting samples. From these data, a graph of the compressive strength sample of beam casting is made, then it is compared with the graph of the compressive strength sample of column casting. The results of the study concluded that using different vendors for casting different components of the building has a greater chance of producing a weak beam-strong column structure.

INTRODUCTION

A large number of victims of disasters (earthquake), especially due to being crushed or trapped in collapsed buildings, is a sign that not all multistorey buildings in Indonesia are perfectly resistant to earthquakes. A building is said to be earthquake resistant if it has nodal points with columns that can withstand loads greater than the beam (Prastowo et al., 2019). Such a building is known as a strong column-weak beam. During withstanding earthquake loads (seismic), building designs that are designed as strong-weak beam-columns can distribute seismic energy uniformly (Lizundia et al., 2015). Seismic energy is absorbed and dissipated through the plastic hinge that is formed at the connection between the beam and the column (Fujino, Siringoringo, Ikeda, Nagayama, & Mizutani, 2019). According to his philosophy, the planning of a strong column-weak beam construction will be achieved if the flexural strength capacity of the beam is smaller than all the joints in the column (Sari, Prastowo, Junaidi, & Machmud, 2020). In this way, during an earthquake, the formation of 'plastic hinges' in the beam structure will be greater than that in the column. Because the column can withstand a greater load than the beam when it experiences a failure the beam structure will first reach a plastic condition; while the column which functions as building support has not yet reached its plastic condition. The formation of plastic hinges dissipates seismic energy and causes the building to change its inelastic shape, thus giving the occupants enough time to vacate the building; because the first time a plastic hinge is formed on the floor of the building at the very top; and before the occurrence of plastic hinges on the lowest floor, the structure of the building can still stand longer without collapsing (Otani, 2008). So even though the condition of the building was badly damaged, it did not collapse causing any casualties.

In the construction implementation, the difficulty in obtaining a strong-weak beam-column construction is at the time of casting the concrete, because when calculating the structure, the planning consultant generally uses the same concrete quality for all types of calculation of the building's structural components (Gridley & Osborn, 2000; Mahadik & Bhagat, 2020; Sherpa, 2010). But in reality, it is possible that the results of the compressive test of concrete samples from one another have strength above the required quality but with a significantly different range of compressive test results. For example, one concrete sample has a strength of 10 MPa above the required concrete quality, while the other concrete sample is only 1 Mpa above the required compressive strength. Because casting is carried out when the concrete is still in fresh condition, the quality of the concrete used is not known with certainty (Mahla, 2018; R & Arulraj, 2020). This ignorance allowed the higher strength concrete to be used in beam casting and a lower one for column casting. The compressive strength test of the sample is carried out three to 28 days later, of course, the concrete columns and beams are dry and hardened. As a result, when it is known that the objective of obtaining the construction of a strong-weak beam-column building has not been achieved, it is no longer possible to repair the hardened concrete other than by dismantling it and then re-casting it.

This study explains the evaluation of a foundry work method in a four-story building located on a college campus in Malang City. One of the departments on the campus is civil engineering, so project supervision involves several technical team members who are lecturers of concrete construction (Hamid et al., 2019; Haseeb, Xinhailu, Khan, Ahmad, & Malik, 2011). In practice, supervision of project implementation has become tighter; One of the requirements that must be fulfilled is to produce a building construction following the building planning consultant's calculation method, namely the construction of strong-weak beam-columns.

In connection with the effort to produce strong-beam column construction, several previous studies mentioned the difficulties in casting work (Dar, Dar, Qureshi, & Raju, 2013). If the floor slab is placed into one unit with the beam, it will cause the beam resistance moment to become stronger, which in turn results in the construction of the strong-weak beam-column turning into a weak column-strong beam (Otani, 2008). A strong-weak beam column structure can be formed if the ratio of the strength capacity of the joint between the beam and the column is more than one (Lu & Cai, 2019). The strong-beam-weak column planning according to one country uses different strength ratio capacity values, and the difference is relatively large (Fujino et al., 2019). ACI 318-14 specifies 1,2; Euro code and New Zealand Code set 1.3; whereas according to the Indian Standard (IS) the amount is 1.4 (Otani, 2008).

The problem is that the field implementer cannot know which country's regulations are used to plan the building he is working on so that he does not know how much difference in the quality of the concrete required for casting columns and beams, to obtain a strong-weak beam-column construction. The practical way and it is the task of the field supervisory consultant is to check the suitability of the implementation in the field with the dimensions of the structure and area of reinforcement in the drawing from the planning consultant (Sari et al., 2020), if it is suitable then casting can be done. After the results of the concrete quality test for casting are known, the magnitude of the joint strength capacity between the beam and the column can be calculated. So, the task of the field executor is to carry out a casting where the quality of the concrete in the casting of the column must be higher than the quality of the concrete for casting the beam. In this case, the planning consultant has determined the requirement that all casting of building structures use K300 grade concrete (Usman, Fifing, Supriyadi, & Sakinah, 2018).

In the field implementation in the first weeks, casting only used ready mixed concrete from one vendor. It turns out that this method creates difficulties, especially in identifying objects when you want to know the quality of the concrete from the casting of each building component, because most of the labeling of the test objects does not specifically mention what casting the sample was made for (Otani, 2008). Many label writings can be interpreted as double; for example, a sample labeled ‘column/beam’. Such labeling raises doubts, whether the test object is to represent the concrete quality test sample on the beam, or is the concrete quality test on the column (Sadjab, Indrayana, Iwamony, & Umam, 2020). By the field executor, the test data is then used to prove that the casting has produced a strong-weak beam column structure as requested. If the data used is not clear, it will certainly result in dubious interpretations. To overcome these difficulties in subsequent work, each casting of different building components uses ready mixed concrete made from different vendors (Handayani & Puspasari, 2020). This study aims to find the most effective concrete casting method that results in the construction of strong-weak beam-columns as intended above.

METHODS

The specimen is a standard size concrete cylinder. Evaluation of the quality of the concrete on the 1st and 2nd-floor beams using 25 test objects, and for the column samples using 20 test objects, made by one ready mixed concrete vendor, the concrete supplier for casting floor 1 and 2. In the 3rd floor casting, the concrete quality samples for The column uses 17 specimens made by the new ready mixed concrete vendor, and for the portal beam, the sample uses 12 specimens made by the old vendor that supplies fresh concrete on the 1st and 2nd-floor foundry work (Kusuma, Soemardi, Pribadi, & Yuliar, 2019).

To determine whether there is a difference or not in the quality of the concrete produced from the two concrete vendors used, a different test is performed using a different number of samples (n). Evaluation to determine the probability of casting carried out to obtain a strong-weak beam-column construction system is carried out in the following order:

- Make graphs of the test results of the compressive strength of column and beam samples;
- calculate the mean compressive strength ($\mathbf{s}_{bm}$) and standard deviation of concrete samples;
- calculate the coefficient of variance in the quality of the concrete;
- statistical evaluation, regarding the quality of the concrete used in casting beams and columns;
- determine the maximum limit probability ($\mathbf{s}bk_{max}$) and the minimum limit ($\mathbf{s}bk_{min}$) the compressive strength of the concrete in the column with a 5% probability of error according to the formula:

  $\mathbf{s}'bk_{max} = \mathbf{s}_{average} + 1{,}64 \times SD$

  $\mathbf{s}'bk_{min} = \mathbf{s}_{average} - 1{,}64 \times SD$ [N.I-2., 1971; 40]
- draw outlines of (1) maximum strength ($\mathbf{s}bk_{max}$); (2) average ($\mathbf{s}_{average}$); and (3) minimum strength line ($\mathbf{s}bk_{min}$) column, into the graph of the test results of the compressive strength of the beam sample (Otani, 2008).

From the graph, it can be interpreted that the part of the graphic which is located beyond the upper limit of the maximum strength of the column is the part that is confirmed as a weak-strong beam column structure. On the other hand, the part of the graph which is located below the minimum limit of column strength is a structure with a strong-weak beam characteristic (Sabara, Junaidi, & Umam, 2018).

RESULT AND DISCUSSION

Casting Using One Concrete Vendor (Ready Mixed)

Figure 1 is a graph of the results of testing the compressive strength of concrete samples for casting floors 1 and 2 using ready mixed concrete made from one of the ready-mixed vendors in the city of Malang. In Table 1, descriptive information is provided about the results of statistical calculation of the concrete quality samples used in the intended casting of columns and beams. Based on the Table 1, it is known that the average compressive strength of concrete samples in the casting of the 1st and 2nd floor beams is 459.71 kg/cm^2; with a standard deviation (SD) of 93.04 kg/cm^2; and the average compressive strength of concrete samples in the column casting is 408.57 kg/cm^2 with SD 46.86 kg/cm^2.

To calculate the sample variance, the formula is used: Variance = (SD / Average). From the results of calculations using this formula, the value of the variance in the quality of the concrete in the casting block is 0.2024, and for the column, the amount is 0.1147. The results of these calculations show that the variance of the concrete quality in the casting of columns and beams is not the same. By looking at the magnitude of the variance value of the concrete strength test sample in beam casting which is 20.24% and column casting of 11.47%, it is statistically significant that the homogeneity of the quality of the concrete in column casting is more uniform than the homogeneity of the quality of the concrete used in beam casting.

Table 2 displays information in the form of the value of the statistical test results required in further statistical analyzes. Table 2 displays the values written on several rows and columns that need to be considered when performing statistical calculations; The values referred to include: (1) the value on the Equal variances assumed line; (2) the value on the Equal

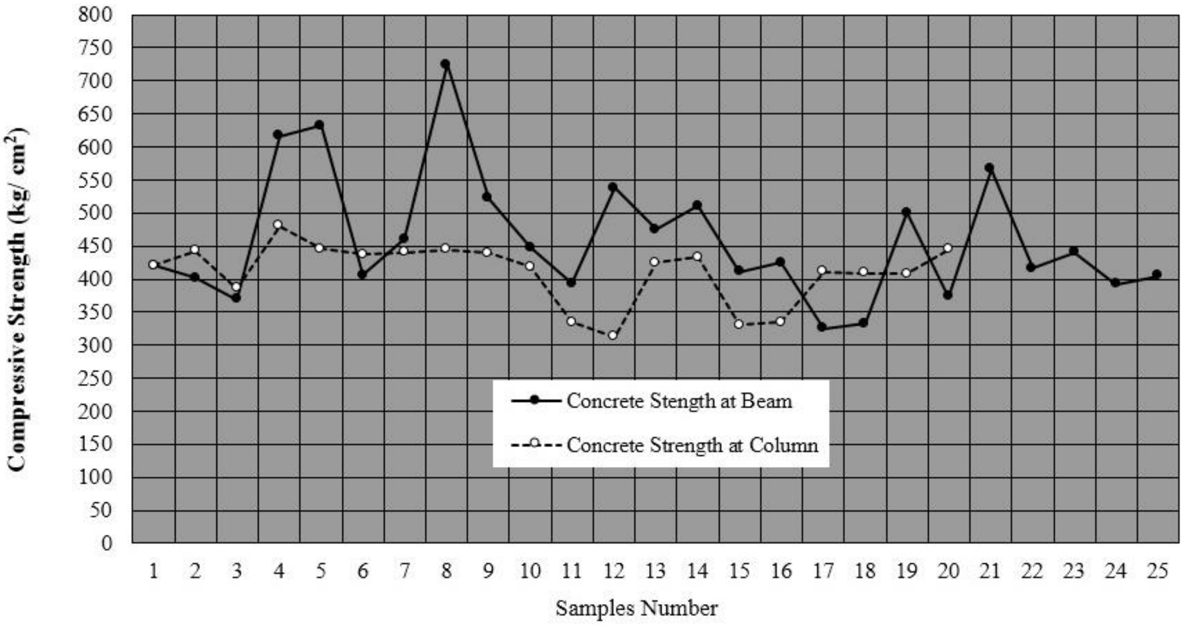

Figure 1. Graph of Concrete Sample Compressive Strength on Foundry Floor 1 & 2
Source: Analysis Data of this Study, 2021.

Table 1. Description of the Quality of Concrete in the Casting of Beams and Columns Floor 1 & 2

	Structure Components	N	Mean	Std. Deviation	Std. Error Mean
Compressive Strength	Block Samples	27	4.5971E2	93.04269	17.90607
	Column Samples	29	4.0857E2	46.86311	10.47891

Source: Analysis Data of this Study, 2021

Table 2. Magnitude Value for Quality Analysis of Concrete on Foundry Columns and Beams Floor 1 and Floor 2.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Compressive Strength	Equal variances assumed	5.311	.026	2.251	45	.029	51.14561	22.71667	5.39189	96.89934
	Equal variances not assumed			2.465	40.378	.018	51.14561	20.74693	9.226872	93.06450

Source: Analysis Data of this Study, 2021

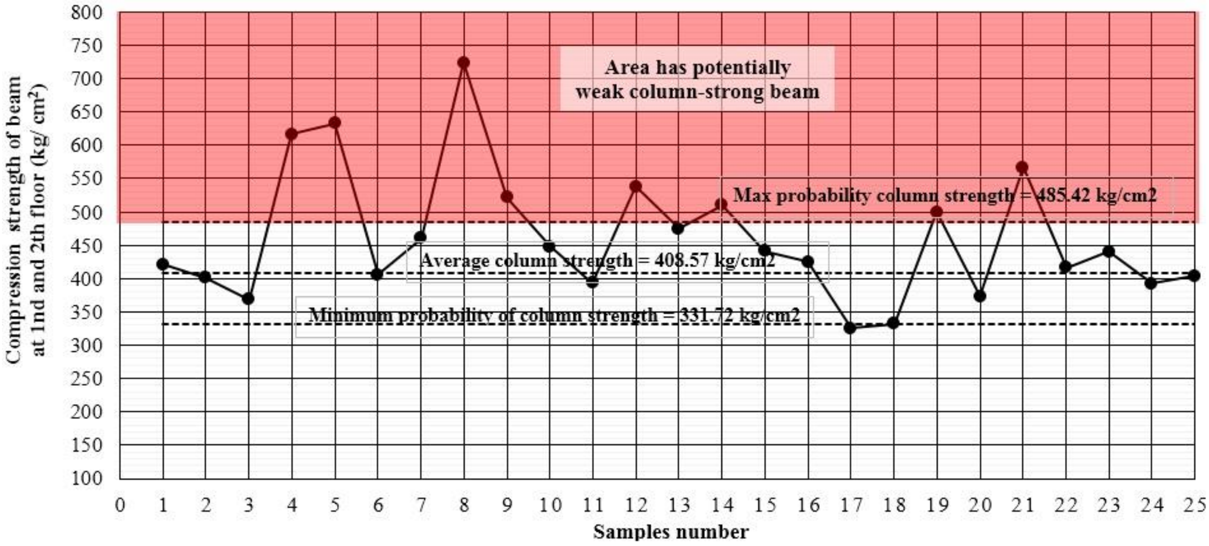

Figure 2. Graph of Chances of Occurrence of Weak Columns of Strong Beams in Castings Using One Ready Mixed Concrete Vendor
Source: Analysis Data of this Study, 2021

variances not assumed line, and (3) the value in the Levene's Test for Equality of Variances column.

The value in the Equal variances assumed line is used if the calculation results in the quality variance of the casting concrete for columns and beams which are statistically the same price. The value on the line Equal variances not assumed is used if statistically, the large variance of the concrete quality sample in the casting of columns and beams is not the same. The value in the column Levene's Test for Equality of Variances is used if you want to know whether statistically, the variance of the sample quality of concrete for casting column and beam is the same or not the same; If the significance value in the Levene's Test for Equality of Variance column is less than 0.05, it means that statistically the quality of the concrete in the column and beam casting is not the same. Vice versa; if the magnitude is more than 0.05, it means that statistically, the variance of concrete quality samples for casting columns and beams is the same (Usman et al., 2018).

From Table 2, it is known that Levene's Test for Equality of Variances column is written a significance value (sig) of 0.026. The value is less than 0.05; this means that statistically, the quality of concrete samples for casting columns and beams for floors 1 and 2 have different variances. Because the variance is different, for subsequent statistical calculations the number of numbers written on the Equal variances not assumed line is used. In that line, the sig value is 0.018, while the t count (t) is 2.465, and the degree of freedom (df) is 40.376. Statistical evaluation to determine whether or not the quality of the concrete used in the casting of columns and beams is carried out by comparing the amount of t calculated in Table 2 column t, with the size of the t table which can be seen in the statistical books in the appendix. If the value of t is greater than the t table, it means that the casting of columns and beams uses concrete of different quality. Conversely, if the calculated t value is smaller than the t table, it means that statistically the column and beam casting have used the same concrete quality.

From the t table, with a value of df = 40.378 and a significance level of 0.05, the t table price is 1.68385. From Table 1b in column t, the amount of t is written as 2.465. It turns out that the value of the t count (magnitude 2.465) is greater than the t table (amounting to 1.68385). This means that statistically, the concrete used in column and beam casting is not of the same quality.

According to Table 1, the average quality of concrete for beam casting is 459.71 kg/cm^2 and for the column, casting is 408.57 kg/cm^2. Considering that the quality of the concrete in the column is lower than that of the concrete in the beam, it can be concluded that statistically casting has the potential not to produce a weak beam strength column structure. To strengthen the correctness of these conclusions, control is carried out by making a graph of the results of the beam compressive strength test, then given three horizontal lines, namely: (1) a line that states the average value of the quality of the concrete in column casting, (2) a line that states the upper limit of the probability of occurrence highest concrete quality in column casting (**s'**bk$_{max}$) which is calculated according to the formula **s'**bk$_{max}$ = **s**$_{average}$ + 1,64 x SD, and (3) the line representing the lowest limit (lower limit) of the probability of the lowest concrete quality (**s'**bk$_{min}$) on column casting. The amount **s'**bk$_{min}$ = **s**$_{average}$ - 1,64 x SD.

Referring to Table 1, the average quality of concrete (**s**$_{average}$) used for casting the column is 408.57 kg/cm^2 and SD is 46.86311 kg/cm^2 so that the upper limit of the probability of the compressive strength of the column sample can be calculated. Based on the results of the calculation, the probability of the upper limit of the compressive strength of the highest column sample is 485.42 kg/cm^2, and the probability of the lower limit is 331.72 kg/cm^2. In Figure 1b. a graph of the probability of casting a beam that has greater strength than the column or the so-called weak column structure of a strong beam is given. From the graphic image, it can be seen that most of the concrete samples are in the part where the weak-strong beam-column construction is likely to form.

Casting Using Different Ready Mixed Concrete Vendors

The use of different ready mixed concrete vendors was carried out in beam and column casting on the 3rd floor. The casting of the column structure on the 3rd floor was carried out by a new concrete vendor, and casting of the beam structure was carried out by the old concrete vendor. Figure 3 presents a graph of the results of the concrete sample compressive strength test on the foundry column and floor beam 3. Descriptive information on the statistical calculation results of the quality of the concrete used in the casting on the 3rd floor is shown in Table 3. From this table, it can be seen that the casting of the column using an average concrete quality of 420.34 kg/cm^2 and SD of 66.2896 kg/cm^2, and casting of blocks using an average concrete quality of 417.71 kg/cm^2 and SD of 78, 8299.

If the average quality of concrete in the column casting is 420.34 kg/cm^2 and SD is 66.28965 kg/cm^2, from the calculation of the variance coefficient of the concrete quality used, is 0.1577 (15.77%). The average quality of concrete in block casting was 417.71 kg/cm^2 with SD 78.82995; If calculated, the coefficients of the variance of the concrete quality will be 0.1887 (18.87%). The quality variants of the concrete used by the two ready-mixed concrete vendors are only slightly different, which means that the homogeneity of the quality of the concrete used in the casting of columns and beams on the 3rd floor is different.

When viewed from the results of numerical calculations, the variance in the quality of the concrete used in beam and column casting is indeed different. However, statistically, there is a possibility that these things are categorized as no different. To ensure certainty, it can be checked in the column Levene's Test for Equality of Variances significance (sig) in Table 4. According to the table, the magnitude of sig = 0.394; because this value is greater than

Table 3. Description of the Quality of Concrete in the Casting of Beams and Columns, Floor 3

	Structure Components	N	Mean	Std. Deviation	Std. Error Mean
Compressive Strength	Block Samples	17	4.1771E2	78.82995	19.11907
	Column Samples	12	4.2034E2	66.28965	19.13617

Source: Analysis Data of this Study, 2021

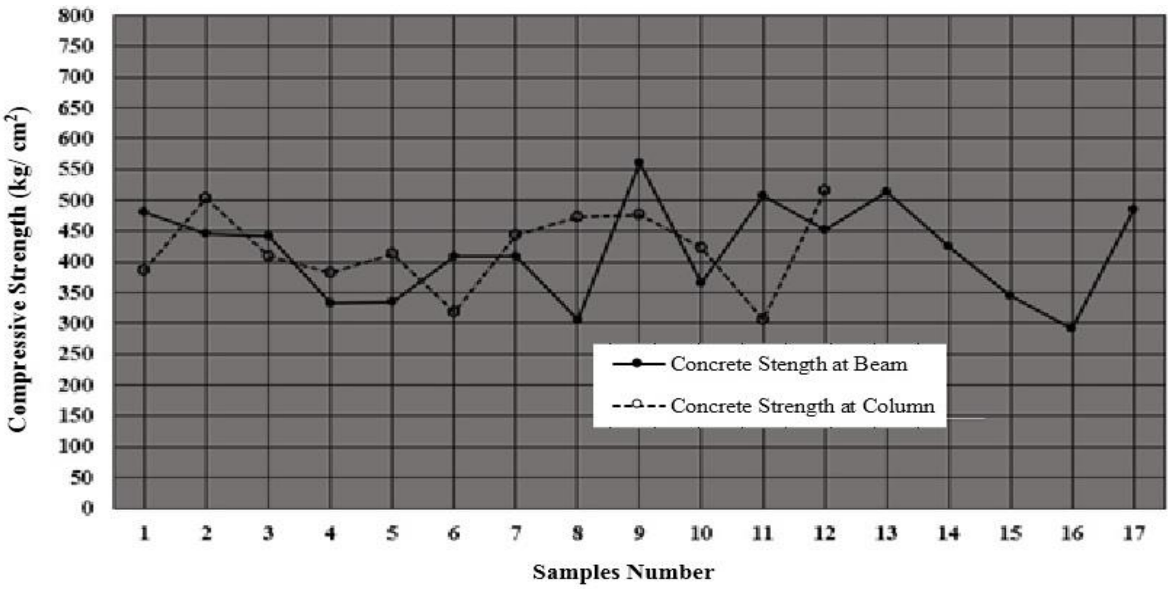

Figure 3. Graph of the Compressive Strength of Concrete Samples on the Foundry Floor 3
Source: Analysis Data of this Study,2021

0.05, it is concluded that the quality of the concrete used in the casting of columns and beams on the 3rd floor has the same variance. In other words, it can be written that statistically the casting of columns and beams on the 3rd floor is carried out with the same homogeneity of concrete quality. To find out whether or not the quality of the concrete used in the casting of columns and beams on the 3rd floor is used, the t value in Table 4 (magnitude -0.94) is compared with the t value in the table (t table).

Statistically, the quality of the concrete used in column and beam casting has the same variance. Therefore, to find the t table, the sig and df values in Table 4 are used in the Equal variances assume line. With significance = 0.05 and degree of freedom (df) = 27 according to obtained t table price of 1.70329; if depicted in a number line range t table from - 1.70329 to + 1.70329. If according to Table 4 the amount of t count = - 0.94 this means that t count is in the range t table, so statistically it can be concluded that the casting of columns and beams on the 3rd floor uses no different quality of concrete (of the same quality).

For this conclusion to be more convincing, control was carried out by drawing a graph of the concrete quality sample on the 3rd-floor beam foundry, with a line stating the average quality of the concrete used in column casting with an upper limit (**s'**bk_{max}) and lower limit (**s'**bk_{min}) probability of the quality of the concrete according to the formula previously written above. If according to Table 3, the average quality of the concrete in the column casting is equal to 420,34 kg/cm^2, and SD = 66,289 kg/cm^2, then the magnitude of the upper limit of the probability of the average quality of the

Table 4. Magnitude Value for Quality Analysis of Concrete in Foundry Columns and Beams Floor 3

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Compressive Strength	Equal variances assumed	.751	.394	-.094	27	.926	-2.62926	27.89244	-59.85982	54.60129
	Equal variances not assumed			-.097	26.065	.923	-2.62926	27.05055	-58.22567	52.96714

Source: Analysis Data of this Study,2021

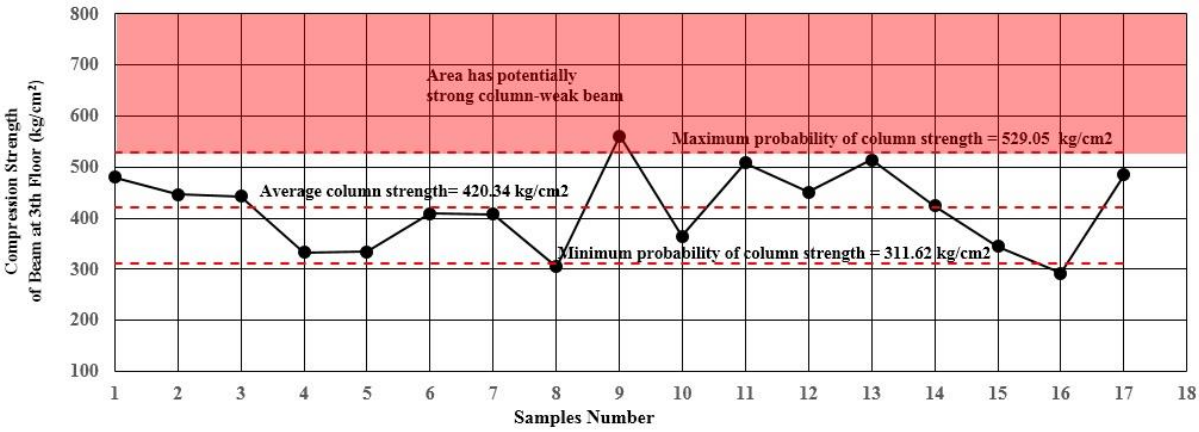

Figure 4. Graph of Chance of a Strong Beam Weak Column in a Casting Using Two Ready Mixed Concrete Vendors
Source: Analysis Data of this Study, 2021

concrete (**s'**bk$_{max}$) = 529,05 kg/cm^2, and the lower limit of the probability of the average quality of the concrete (**s'**bk$_{min}$) the amount of value 311,62kg/cm^2.

From Figure 4, it can be seen that statistically casting has the opportunity to produce a strong column structure as weak beams as requested. This construction can be achieved after each column casting and beam casting using different ready mixed concrete vendors. This is because each vendor knows exactly what component casting the concrete sample is used for so that one sample of the test object represents only one item of casting work performed. This way the sample can be identified.

CONCLUSIONS, RECOMMENDATIONS, AND LIMITATIONS

The results of the study provide very interesting information. The building components that are cast consist of beams; columns; and floor slabs. Because the beam structure and floor slabs are one unit, casting uses only one concrete vendor; while in column casting a different concrete vendor is used. In this way, each vendor knows exactly what casting the concrete is used for. This method makes it easy for anyone who wants to know the results of testing concrete quality samples in beam and column casting so that the evaluation of the intended strong-beam column building structure can be known with certainty. The observations show that using different vendors for casting various building components has a greater chance of producing a weak strong-beam column structure.

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