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The Effectiveness of the Recycled Aggregate on the Story Lateral Displacement and Story Drift of High-Rise Buildings

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Abstract: The present paper examines the effect of Recycled Aggregate (RA) on the story displacement and story drift of a 17-story high-rise building exposed to wind loads in both directions. For this purpose, four percentages of RA were used (0, 25, 50, and 100%), and four ETABS models were built according to these percentages. The lateral displacement increased with the percentage of RA, reaching 25.19% higher than the natural value at the roof when using 100% recycled aggregate. The shear walls' distribution has an effect on the displacement in each direction. The y-direction had a higher displacement because the walls act as lateral bracing and play a significant role in structural stability. The story drift had a similar behaviour to story displacement, displaying a 25% increase compared to the natural state when using 100% recycled aggregate. Additionally, all models met the serviceability and safety requirements, and thus, the recycled aggregate may be used in reinforced concrete high-rise buildings. Finally, the optimised aggregate replacement ratio in concrete mix was between 25% and 50% to strike a balance between environmental benefits and structural performance.

***Keywords**: Recycled Aggregate, Story Displacement, Story Drift, High-Rise Building, ETABS Model, Structural Performance, Reinforced Concrete, Structural Stability, Replacement Ratio.*

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I. INTRODUCTION

The construction industry has been increasingly turning to using sustainable materials to minimise environmental impact and encourage resource efficiency. Recycled concrete aggregate (RCA), resulting from the demolition of buildings and roads, has gained attention as a practical alternative to natural aggregate. The RCA offers environmental benefits, including reduced landfill waste and lower carbon emissions. The performance of structural elements (e.g., beams and columns) of RCA remains a subject of research.

Recycled aggregates are materials obtained from the destruction of old buildings and roads. This debris is usually considered as disposed of and worthless materials. It includes crushing concrete, bricks, asphalt, and other construction debris, as shown in Figure 1, and is a sustainable method for producing reusable aggregates for construction purposes.

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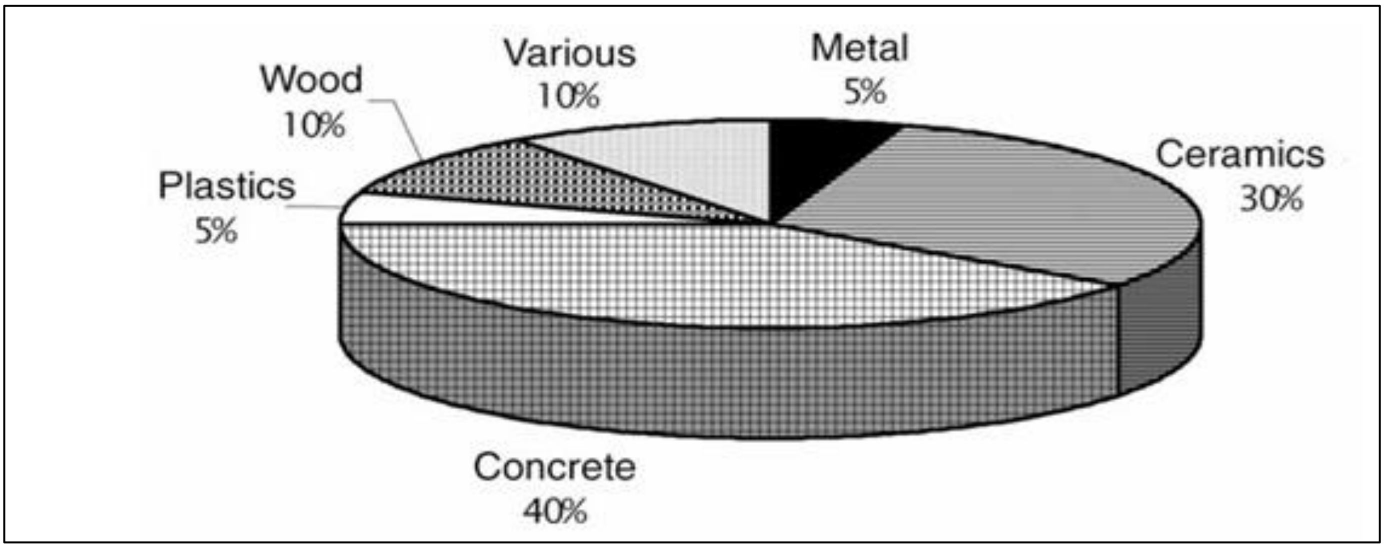

Fig 1 Demolition Waste Basic Composition [1].

The first use of recycled aggregates was in 1970 in the USA because the landfills refused to accept the broken concrete due to space consumption. Figure 2 presents the recycled aggregate consumption in different countries worldwide in 2014; the largest consumption was approximately 10.5 million tons of recycled aggregate in China, while the lowest consumption was in Northern Europe.

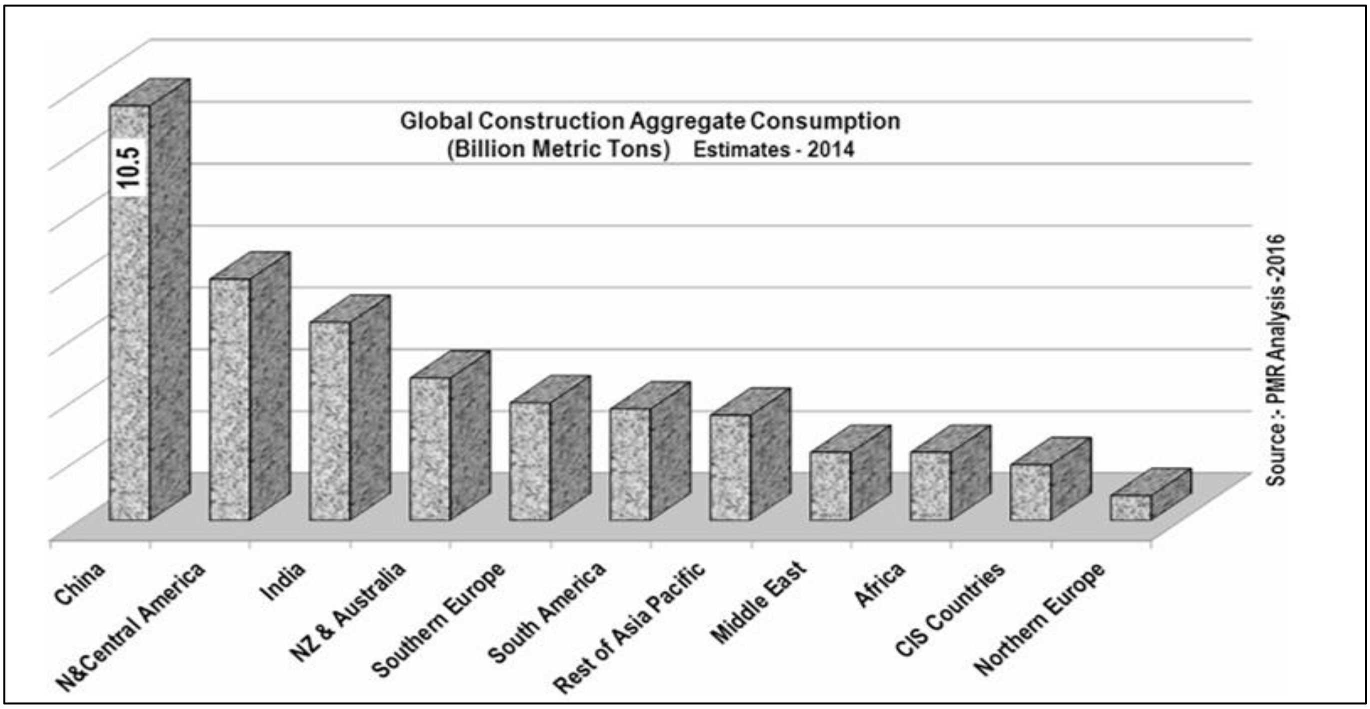

Fig 2 Worldwide Consumption of RA as Reported by [2].

The figure above shows the total aggregate consumption in Europe in 2015; the highest aggregate production was 545 million tons, with 68 million tons of recycled aggregate production. The lowest aggregate production was in Ireland, at 28 million tons, with no production of RA.

The implementation of incorporating the RA into concrete fabrication has several benefits. The first benefit is its effect on the environment by reducing waste and conserving resources through reduced aggregate demand. Additionally, the use of RA leads to a reduction in carbon dioxide emissions compared to natural materials during the production process, from extraction to use. Another benefit to add is the cost-effectiveness of using recycled aggregates compared to natural aggregates, which can be suitable for areas suffering from material scarcity, high costs, or transportation obstacles. RA can achieve comparable performance to the natural aggregates by proper processes and good quality control.

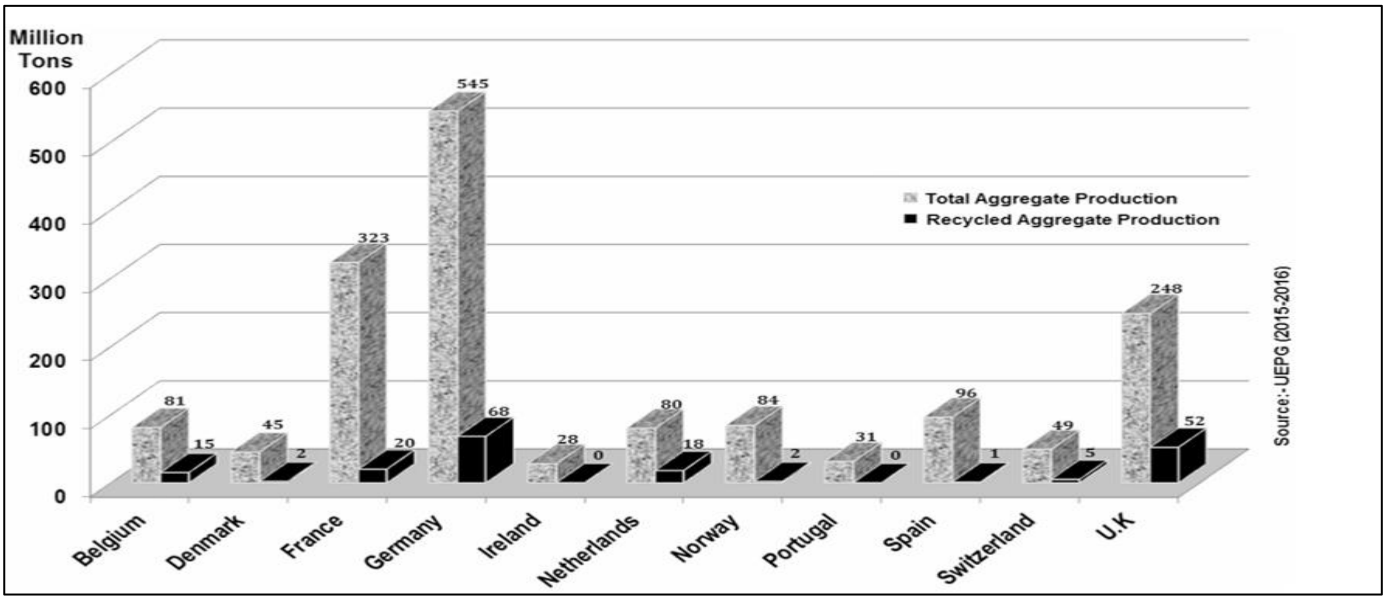

Fig 3 Amount of Total and Recycled Aggregate used in Some Countries in 2015

The uses of recycled aggregates are numerous in the construction industry. They may be applied on structural elements like beams, columns and slabs. Furthermore, they can be used in the construction of infrastructure projects, such as pavement layers and road bases. Recycled aggregates are used to produce products such as concrete blocks and drainage pipes in the precast industry. On non-structural applications, they are usually used on items such as sidewalks and curbs where the performance needs are not as stringent. Finally, the size of recycled aggregates for either structural or non-structural applications has been dependent on their mechanical properties and the quality control measures.

The implementation of recycled aggregates faces some challenges during the implementation process. The first challenge to mention is that the variable quality of the recycled aggregates has significant variation due to differences in material sources, extraction methods, and the level of contamination. The second challenge to address is their lower mechanical properties compared to natural aggregates, which affect performance and necessitate some adjustments during concrete mix design. This encompasses a lower density and increased water absorption. Moreover, the durability of concrete has been affected by the existence of old mortar and unexpected contaminations, especially in harm environments. The recycled aggregates proper selection and treatment of recycled aggregates is recommended to tackle these concerns. Finally, the approval of using recycled aggregates is affected by industry standards and regulations; their development is vital to accept their use globally.

Table 1 illustrates the characteristics of natural and RA, including saturated surface-dry density, oven-dry density (kg/m³), wetting capacity of water, aggregate dimensions, and replacement ratios. As can be observed, natural aggregates have superior dry densities (oven-dried and saturated surface-dried) relative to recycled aggregates. The feat of this variability primarily lies in the fact that recycled aggregates have a porous and rough texture, which is also the reason for their greater water absorption. The maximum particle size is usually larger in natural aggregates, whereas the minimum size remains similar to that of the two types. Finally, the percentage degree of natural aggregates replacing them with recycled aggregate is different and can even be up to 100 percent as well.

Table 1 Comparative Characteristics of Natural and Recycled Aggregates [3].

Property	Aggregate type	Minimum	Maximum
Saturated-surface-dry density (kg/m³)	Recycled	2300	2750
	Natural	2400	2700
Oven-dried density (kg/m³)	Recycled	2100	2640
	Natural	2500	2700
Water absorption of aggregates (%)	Recycled	3.52	7.55
	Natural	0.5	2
Dimensions of aggregate (mm)	Recycled	4	30
	Natural	4	37.5
Percentage replacement (%)	Recycled	10	100
	Natural	N/A	N/A

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Aggregate durability is usually checked by the crushing strength and the Los Angeles abrasion test. Recycled aggregate concrete would have higher values in both tests than those of the natural aggregate. This has a lot to do with the metallic effect of steel balls in the process of abrasion, which makes the recycled material lose more of its surface. Due to this, increased proportions of fine particles are yielded by recycled aggregates. It is mentioned that crushed aggregate value is around 23.1 and 32 percent [3]**;** [4]**.** Such high values are explained by the presence of residual mortar which undermines the interfacial transition zone, zone-the most easily cracking aggregation in the aggregate. On the other hand, the Aggregates obtained naturally have lower crushing values in the absence of such a surface coating. The recycled aggregates have a residual mortar layer, which not only lowers their strength but also leads to weak bonding internally within the concrete.

Table 2 illustrates the mechanical properties of recycled and natural concrete aggregate. Natural concrete aggregate has a fresh density than the RA. Additionally, the workability of natural aggregate ranged from 50 to 150 mm, which is higher than that of the recycled aggregate. The main factor affecting concrete workability is the shape of the aggregates, which differs depending on the method of production of RCA and the crusher used [5]**.** In general, the shaper is angular with smooth sides. Additionally, the compressive strength, tensile splitting strength, and flexural strength of RCA are lower than those of natural concrete aggregate. Amount and properties of RA affect the compressive strength of recycled concrete aggregate. This includes the W/C ratio, the percent of replaced coarse aggregate, and the percentage of the coating layer. Finally, the RCA elastic modulus is less than that of the natural concrete aggregates. The compressive strength is the reason behind this, as the elastic modulus depends on the concrete's compressive strength, which is higher in natural concrete aggregates.

Table 1 Mechanical Properties of Recycled and Natural Concrete Aggregates [6].

Property	Type of aggregate	Minimum	Maximum
Fresh density of the mix (kg/m^3)	Recycled	2017	2478
	Natural	2200	2500
Workability/ slump test (mm)	Recycled	25	140
	Natural	50	150
Compressive strength (MPa)	Recycled	13.9	54.9
	Natural	20	60
Tensile splitting strength (MPa)	Recycled	1.3	4.7
	Natural	2	5
Flexural strength (MPa)	Recycled	2.62	6.3
	Natural	3	7
Elastic modulus (MPa)	Recycled	11300	33500
	Natural	25000	35000
Water absorption (%)	Recycled	1.2	11.8
	Natural	3	5

According to McNeil and Kang [7], recycled coarse aggregates comprising up to 30 per cent of the concrete mixture exhibited similar compressive strength to that of conventional concrete, provided the water-to-cement (w/c) ratio exceeded 0.25. Nevertheless, at the highest proportions of w/c ratio, the compression strength of concrete, which was used with the RAs, was demonstrated to be lower than the ordinary mixes [7].

Exteberria et al. [5] conducted a research study aimed at, among others, assessing the influence of different proportions of using concrete mixed with recycled concrete aggregate (RCA) on the compressive strength. They subjected concrete mixes having 0, 25, 50, and 100 percent of RCA. Their results indicated that even up to 25 percent RCA in replacement of natural aggregate did not cause much difference to the compressive strength. Under the condition of higher replacement ratios, like 50% or more the strength could only be maintained at a similar level when a reduction of the water-to-cement ratio of 4 up to 10 percent was made. Failure to make this adjustment may result in a drop in compressive strength of up to about 25 per cent, and the need to ensure optimisation of the mix design with increased proportions of RCA [5].

These results are in agreement with [7] and [8] for a 100% replacement ratio. Additionally, they found that a 30% replacement caused a reduction in compressive strength of up to 18%. The compressive strength reduction in RCA is because of the increase in water absorption of the RA [9]

Modulus of elasticity, also known as Young's modulus, is influenced by the concrete compressive strength. The modulus of elasticity of recycled coarse aggregates is lower than that of conventional concrete. Frondistou-Yannas [8] reported that the recycled coarse aggregate modulus of elasticity was reduced by 40% compared to the natural concrete [8]. Maruyama et al. [10] reported a reduction of

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about 20% [10]. This variation could be attributed to the different aggregate properties used in these studies. This means that the modulus of elasticity of concrete is mainly dependent on the qualities of the aggregates, specifically their rigidity, rather than the cohesion of the concrete as a whole. The same trend was observed by [11] as presented in Figure 4.

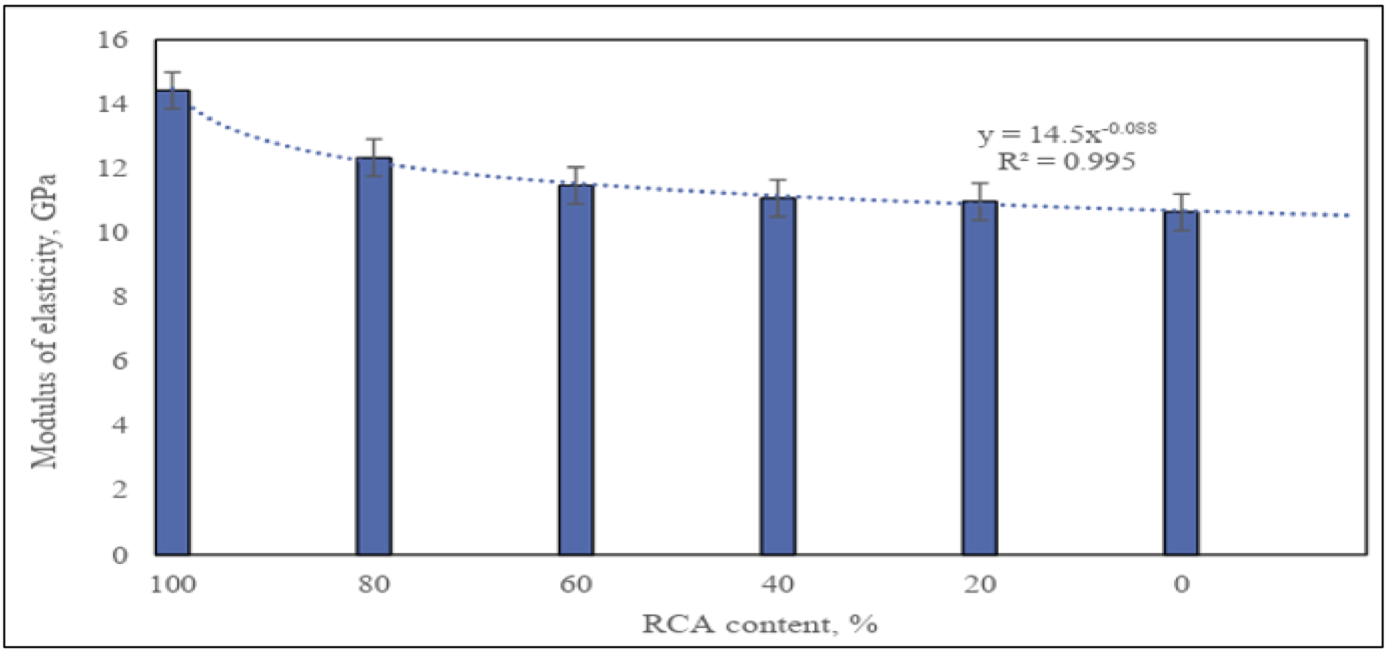

Fig 4 Young's Modulus at Different Recycle Coarse Aggregate Content [11].

In their research, McNeil and Kang [7] noticed that the recycled coarse aggregates have a moderate effect on the modulus of rupture. Posing a replacement level of between 15 and 30 per cent, the decrease in modulus of rupture was, however, observed to be up to 13 per cent. To address these impacts and add more compressive strengths, those supplementary materials like silica fume and fly ash can be injected. These additives have also been seen to enhance the compressive strength by around 15-20 percent more than the usual concrete mixes [7].

Several researchers have reported that reinforced concrete beams made from RAs can be prone to higher deflection compared to beams made from natural aggregates [10] and [12]. This is because it has a lower Young's Modulus compared to natural concrete and a higher porosity of RA [10]. Under the same load conditions, for instance, an RC beam made from 100% RAs will be prone to deflection higher than a beam made from natural aggregates, which means that the deflection will increase with the increasing replacement ratio of natural concrete.

Fathizal et al. [13] found that the deflection at beam mid-span under 40% failure load was higher in beams made of RA concrete, and the predicted deflection from the ACI code (ACI-318-11) and Eurocode 2 (EC2) is higher than the observed deflection [13]. Abdo et al. [14] reported that their deflections met the acceptable limits required for structural applications [14].

The use of RAs in reinforced concrete beams can affect the width of the cracks and their spacing. Lu et al. [15] found that the crack width is wider in beams made from RAs compared with those made from natural aggregate, yet they still meet the applicable standards and limits [15]. The high porosity and lower stiffness of the RA, which cause an increase in deflection, are the reasons behind this [10].

In addition, the spacing between cracks in beams made from RA is smaller and irregular compared with beams made of natural aggregates. This is because of the existence of old mortar and the non-homogeneous nature of the RAs [16]. Sato et al. [12] found that curing conditions play a role in crack spacing. Dry curing causes a smaller crack spacing compared to wet curing [12].

The RAs that are coarse affect the major structural parameters, such as deflections, width, and spacing of the cracks, as well as the compressive strength. Their application influences both the cracking and ultimate moment strengths of reinforced concrete beams. It is interesting to note that beams with the use of RA would have lower cracking moments, which in turn may result in earlier cracking at some loads. The most common reason behind this conduct is that RAs have lower tensile strength and higher porosity [14]. McNeil and Kang [7] reported that the weaker interfacial zone between the new mortar and the RAs is the reason behind the reduction in cracking moment. Also, they found that the harm of using RCA is limited [7]. Fathifazl et al. [13] relied on visual inspection for experimental cracking moment to state that the cracking moment of the beam made of recycled coarse aggregate is less than that of the beam made from natural aggregates. Additionally, they found that recycled coarse aggregates have a greater impact on the cracking moment than the ultimate moment, as the concrete's strength properties are influenced by cracking [13].

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In addition, the ultimate moment of RA beams could be equivalent to that of beams made of natural aggregates, where the steel yields before the concrete is crushed. This implies that the reconstructed aggregate has a significant influence on the bearing capacity of the beam under overall load [7]**.** To explain, the ultimate moment capacity of the beam, which is at a high percentage of RA, is just a little less than the beam that is made of natural material; such a difference is within the acceptable range of the structural applications. Fathifazl et al. [13] have discovered that the ultimate moment that has been observed is bigger than the estimated ultimate moment [13]. Additionally, Muruyam et al. [10] found that the ultimate moment observed was higher than expected by 10 to 20 per cent [10].

RA provides significant savings in the cost of natural aggregate, making it a smart option for sustainable construction. Ohemeng and Ekolu [17] studied the total cost of natural and recycled aggregates. The cost of coarse natural aggregate was $76.30, and the cost of coarse recycled aggregate was $45.77. The fine natural aggregate cost was $68.05, and the fine RA cost was $34.39. This means that the RA has a total cost less than the natural aggregate by 40% and 49.4% for coarse and fine aggregate, respectively. Then, the recycled aggregate is a good choice from an economic perspective [17].

The implementation of RA in concrete structural elements, such as beams, leads to significant environmental benefits, including minimising construction costs, protecting natural resources for future generations, and reducing greenhouse gas emissions. Therefore, the replacement of natural aggregate with RA will reduce the demand for fresh, virgin aggregate mining. Approximately 20% of the embodied energy of the concrete can be reduced by using RA, thereby contributing to a decrease in overall carbon emissions [18]. Based on transport distance and replacement ratio, carbon dioxide emissions can be reduced by 15 to 22% when using RA in concrete compared with conventional concrete [2]. Finally, the RA implementation enhances the sustainability profile of concrete by improving waste and resource management [19].

The present report investigates the effectiveness of the RCA on the ultimate performance and serviceability of concrete beams, highlighting the knowledge gaps in characterising the mechanical behaviours of structural components subjected to loading. However, the cost-effectiveness and environmental benefits of RCA show different properties, such as high-water absorption, low density, and a lower elastic modulus, compared to conventional concrete. These properties affect the performance of the structural elements.

Past research has focused on the effect of the percentage of RCA on the compressive strength and deflection of beams compared with conventional concrete. However, these effects may be reduced by optimising the partial replacements with an optimised mix design (the replacement is between 25 to 50%). This paper assesses the influence of RCA at different replacement ratios on strength, serviceability, cost and sustainability benefits. Finally, the findings serve as a guide for the lead structural engineer to strike a balance between structural stability and sustainability, offering insights for codes and standards to determine the optimal replacement of RCA in construction. Thus, the main aim of this paper is to investigate what effect the RCA mix can have on the story lateral displacement and story drift of the 17-story rise building under the wind load through the use of ETABS software.

II. METHODOLOGY

In this paper, the four models were built in ETABS 21 software using the material properties provided in the previous section, as shown in Table 3. The concrete compressive strength and Young's Modulus for the concrete of various percentages of RA were collected from empirical data obtained by [20]. This is done to make the results reliable and simulate real conditions as closely as possible. Then, apply the load pattern in both directions. The results from ETABS software will be presented in the following section.

➢ *Materials*

Table 3 illustrates two properties for the concrete used in modelling the building using ETABS software. The steel used in these models has a tensile yielding stress of 500 MPa for flexural and shear reinforcement [5].

Table 3 Compressive strength and Young’s Modulus of natural and RAs

	Compressive strength (Mpa)	Young’s Modulus (Mpa)
Natural aggregate	42	33700
25% Recycled aggregate	42	33200
50% Recycled aggregate	41	31800
100% recycled aggregate	40	27000

➢ *ETABS Model characteristics*

In this paper, four ETABS models were created in order to study the effect of using RA in concrete structures. Figures 5 and 6 present the structural model in three dimensions and the plan view of the building, respectively. Each model consists of 17 floors, with three underground and the rest above ground level. Table 4 presents the stories' characteristics.

Table 4 Stories Characteristics

Tower	Name	Height (m)	Master Story	Similar To	Splice Story
T1	TOP ROOF FLOOR	3.3	No	None	No
T1	ROOF FLOOR	3.4	No	None	No
T1	10TH FLOOR	3.4	No	2ND FLOOR	No
T1	9TH FLOOR	3.4	No	2ND FLOOR	No
T1	8TH FLOOR	3.4	No	2ND FLOOR	No
T1	7TH FLOOR	3.4	No	2ND FLOOR	No
T1	6TH FLOOR	3.4	No	2ND FLOOR	No
T1	5TH FLOOR	3.4	No	2ND FLOOR	No
T1	4TH FLOOR	3.4	No	2ND FLOOR	No
T1	3RD FLOOR	3.4	No	2ND FLOOR	No
T1	2ND FLOOR	3.4	Yes	None	No
T1	1ST FLOOR	3.4	No	None	No
T1	MEZZANINE FLOOR	3.4	No	None	No
T1	GROUND FLOOR	1.95	No	None	No
T1	LOWER GROUND FLOOR	3.49	No	None	No
T1	1ST BASEMENT	3.4	No	2ND BASEMENT	No
T1	2ND BASEMENT	3.4	Yes	None	No

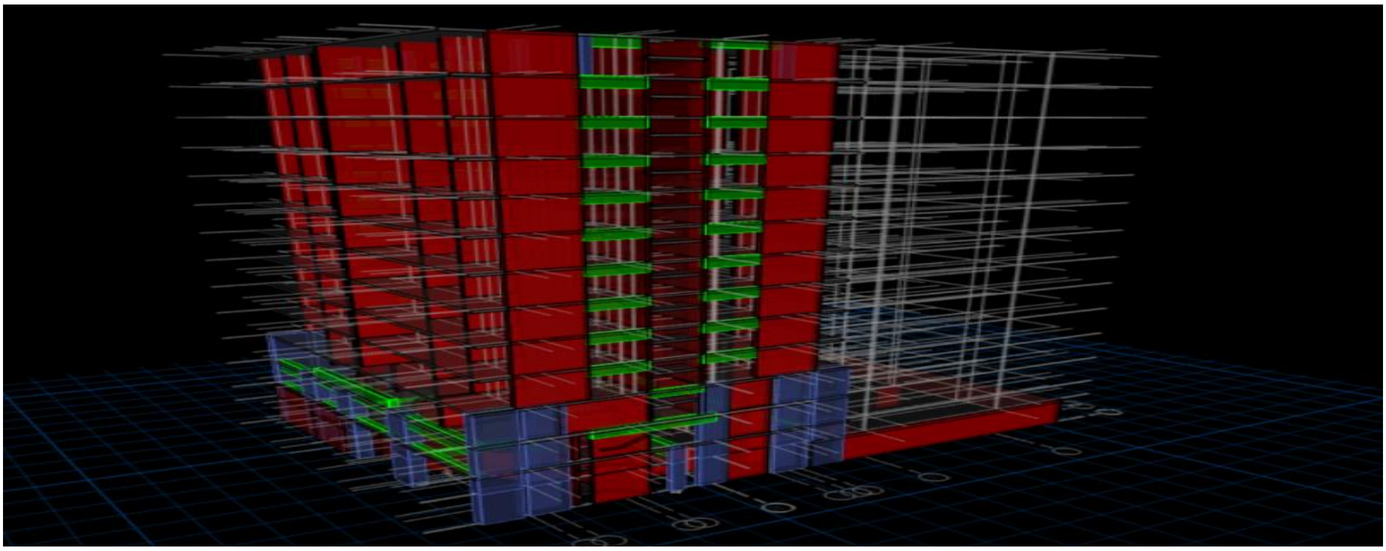

Fig 5 Building in 3D in ETABS.

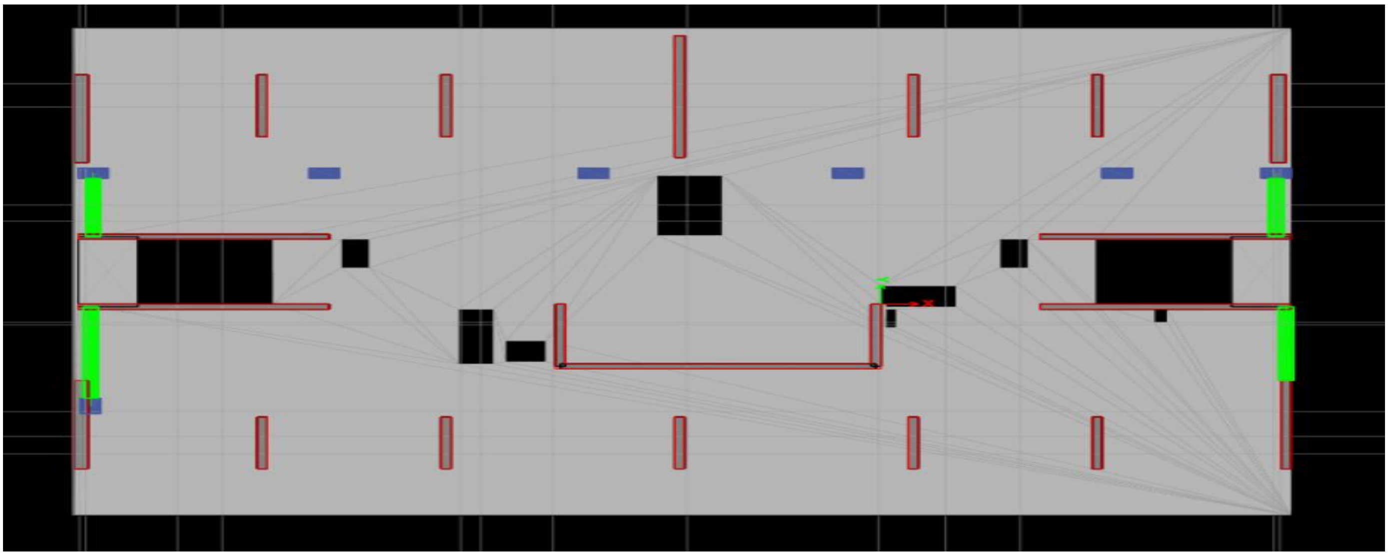

Fig 6 Building Plan in ETABS Software.

As shown in Figure 6, the beams are presented in green, the columns in blue, and the walls in grey, red, and grey colours.

➢ *Load Patterns*

In this paper, the load applied to the building is wind load only. Tables 5 and 6 present the ASCE load patterns applied in the four models in x and y directions, respectively.

Table 5 Wind Load Pattern from ASCE 7-10 in x Direction.

Wind speed	**90 mph**
Exposure Type	C
Gust Factor	0.85
Topography factor	1
Wind Pressure Coefficients	0.8
Leeward coefficients	0.5

Table 6 Wind Load Pattern from ASCE 7-10 in y Direction.

Wind speed	40 mph
Exposure Type	B
Gust Factor	0.85
Topography factor	1
Wind Pressure Coefficients	0.8
Leeward coefficients	0.5

III. RESULTS AND DISCUSSION

After creating the ETABS models for high high-rise buildings, the outputs for using the natural and RA will be illustrated in this section.

➢ *Stories Displacements*

Tables 7 to 8 and Figures 7 to 8 present the story displacements in the y-direction and x-direction, respectively, for the different percentages of RAs.

Table 7 Story Displacement in the y-Direction

Story	Elevation (m)	Location	Natural	25% RA	50% RA	100% RA
TOP ROOF FLOOR	44.55	Top	13.608	13.847	14.433	17.041
ROOF FLOOR	41.25	Top	13.919	14.159	14.762	17.426
10TH FLOOR	37.85	Top	12.809	13.03	13.584	16.036
9TH FLOOR	34.45	Top	11.678	11.879	12.385	14.621
8TH FLOOR	31.05	Top	10.546	10.727	11.184	13.203
7TH FLOOR	27.65	Top	9.409	9.571	9.978	11.779
6TH FLOOR	24.25	Top	8.258	8.401	8.758	10.338
5TH FLOOR	20.85	Top	7.089	7.213	7.518	8.873
4TH FLOOR	17.45	Top	5.898	6.002	6.254	7.381
3RD FLOOR	14.05	Top	4.687	4.772	4.969	5.863
2ND FLOOR	10.65	Top	3.465	3.532	3.674	4.334
1ST FLOOR	7.25	Top	2.265	2.313	2.402	2.832
MEZZANINE FLOOR	3.85	Top	0.959	0.987	1.017	1.2
GROUND FLOOR	0.45	Top	3.009	3.056	3.191	3.764
LOWER GROUND FLOOR	-1.5	Top	0.676	0.68	0.717	0.845
1ST BASEMENT	-4.99	Top	0.052	0.052	0.055	0.064
2ND BASEMENT	-8.39	Top	0.05	0.051	0.053	0.062
3RD BASEMENT	-11.79	Top	0	0	0	0

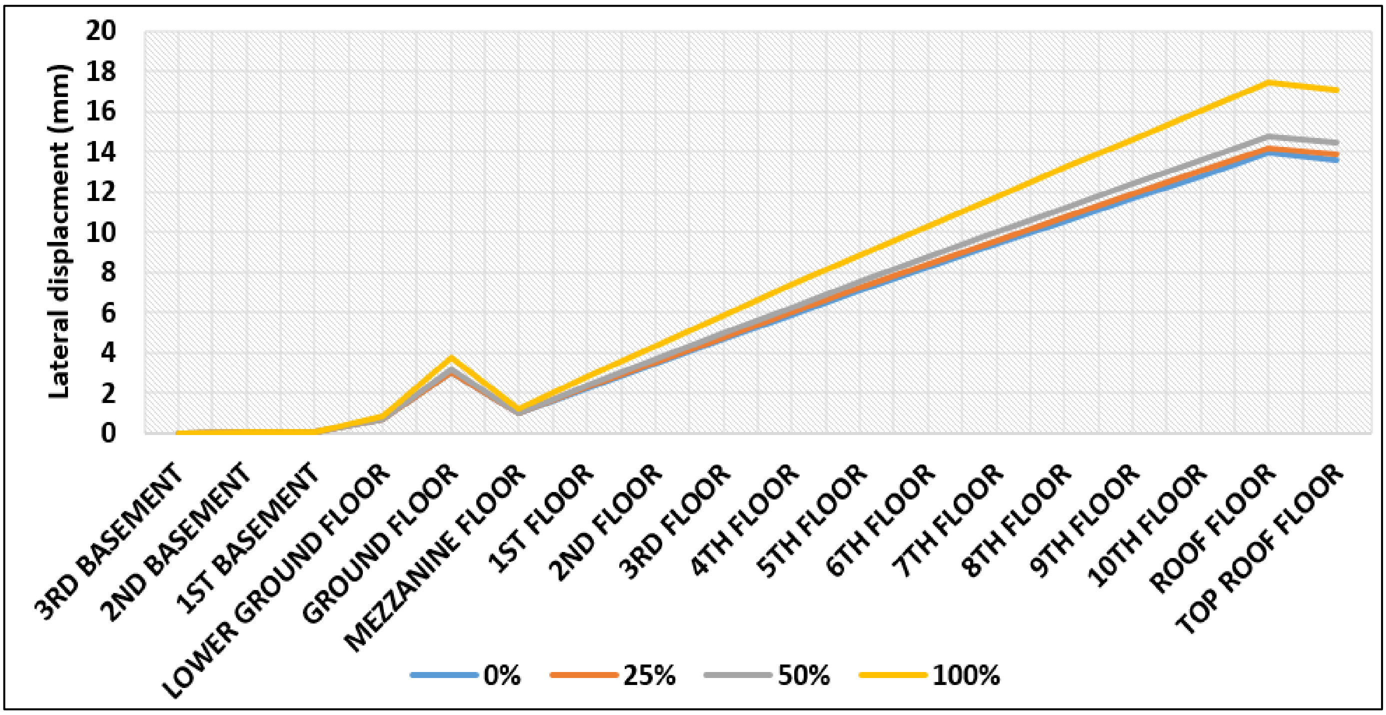

Fig 5 Story Displacement in y-Direction.

Table 8 Stories Displacement in x-Direction.

Story	Elevation (m)	Location	Natural	25% RA	50% RA	100% RA
TOP ROOF FLOOR	44.55	Top	2.117	2.31	2.246	2.652
ROOF FLOOR	41.25	Top	2.339	2.528	2.481	2.928
10TH FLOOR	37.85	Top	2.144	2.325	2.274	2.684
9TH FLOOR	34.45	Top	2.051	2.224	2.175	2.568
8TH FLOOR	31.05	Top	1.954	2.118	2.072	2.445
7TH FLOOR	27.65	Top	1.844	1.998	1.955	2.307
6TH FLOOR	24.25	Top	1.716	1.859	1.82	2.147
5TH FLOOR	20.85	Top	1.566	1.696	1.66	1.959
4TH FLOOR	17.45	Top	1.387	1.503	1.47	1.734
3RD FLOOR	14.05	Top	1.173	1.274	1.244	1.467
2ND FLOOR	10.65	Top	0.918	1.002	0.973	1.148
1ST FLOOR	7.25	Top	0.631	0.698	0.669	0.789
MEZZANINE FLOOR	3.85	Top	0.375	0.391	0.397	0.468
GROUND FLOOR	0.45	Top	1.537	1.573	1.628	1.916
LOWER GROUND FLOOR	-1.5	Top	1.052	1.056	1.115	1.314
1ST BASEMENT	-4.99	Top	0.18	0.183	0.191	0.225
2ND BASEMENT	-8.39	Top	0.168	0.17	0.178	0.209
3RD BASEMENT	-11.79	Top	0	0	0	0

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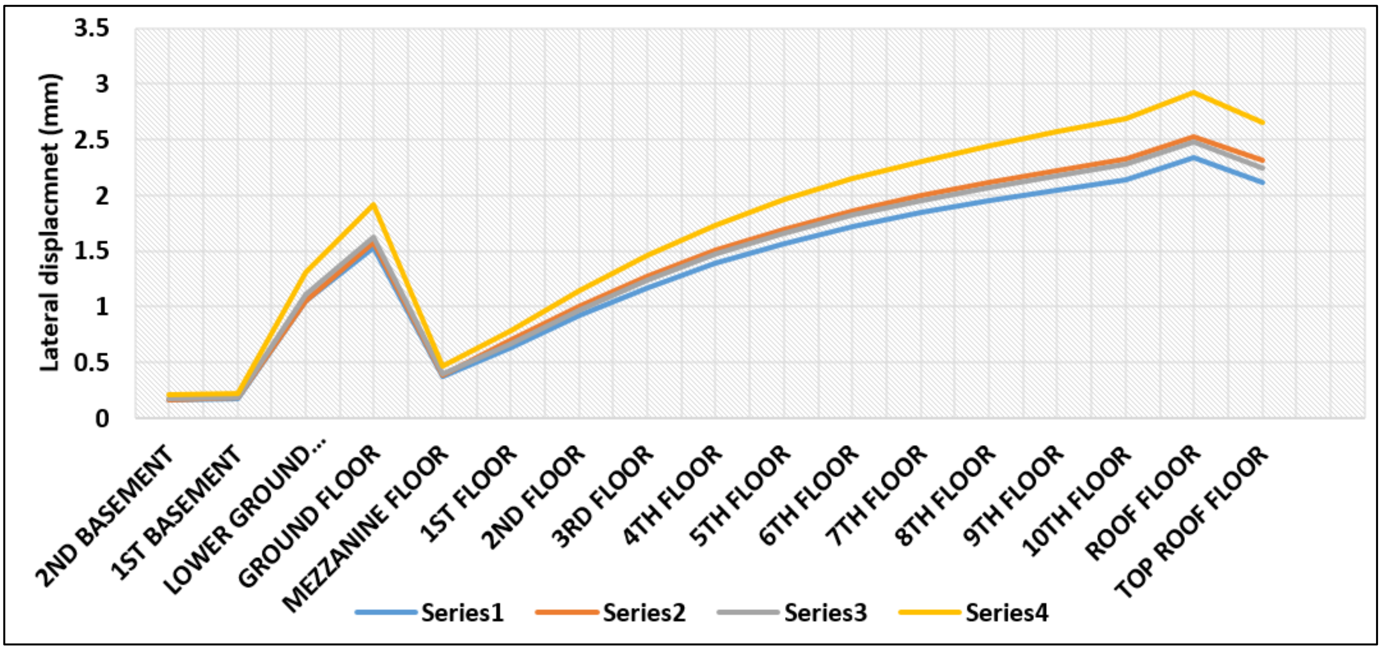

Fig 6 Story Displacement in x-Direction.

From Tables 7 and 8, it was clear that the story displacement in the x and y directions increased with the increase in story elevation for all modes and percentage of aggregate replacement ratio. This is because the applied wind load increased with the increase in story elevation, according to ASCE-07.

For model natural where the concrete was natural the displacement was zero at the top of the 3rd basement floor which is the minimum value of displacement since it was below the ground level and did not subject to wind load, the maximum was 13.919 mm at the top of the building where the elevation was about 41.25m. The displacement in the y-direction is larger than that in the x-direction, though the wind speed in the x-direction was greater than that in the y-direction. This can be attributed to the shear walls that existed in the y-direction more than in the x-direction, which resist the applied wind load from the x-direction.

For 25% RA, the maximum lateral displacement at the top was increased from 13.919 to 14.159mm, which was a little bit of an increase (1.72 %). A 50% replacement ratio presented 14.762mm lateral displacement (6.06%), compared with the natural aggregate. The full replacement ratio showed 17.426mm displacement, which is about 25.19% higher than the concrete building made from natural aggregate.

Additionally, the maximum lateral displacement in the y-direction was 2.339 mm and 2.528 mm when using natural and 25% RA, respectively, showing the same trend as in the x-direction. The 25% replacement ratio resulted in lateral displacement that was higher than the natural by 8.08%. The 50% and 100% replacement ratios showed 2.481 mm (6.08% higher than the natural) and 2.928 mm (25.18% higher) lateral displacement, respectively. These results align with the study by [21].

- *Stories Drifts*

The story drift reflects the story displacement relative to the floor below when subjected to lateral forces like wind load, making it a critical design parameter in designing high-rise buildings. The higher story drift can cause building structural and nonstructural damage. Tables 9 to 10 and Figures 9 to 10 show the stories drift in x and y directions, respectively.

Table 9 Lateral Story Drift in the X-Axis Direction

Story	Elevation (m)	Natural	25% RA	50% RA	100% RA
TOP ROOF FLOOR	44.55	0.000068	0.000069	0.000072	0.000085
ROOF FLOOR	41.25	0.000032	0.000033	0.000034	0.000040
10TH FLOOR	37.85	0.000027	0.000028	0.000029	0.000034
9TH FLOOR	34.45	0.000029	0.000029	0.000030	0.000036
8TH FLOOR	31.05	0.000032	0.000033	0.000034	0.00004
7TH FLOOR	27.65	0.000038	0.000038	0.000040	0.000047
6TH FLOOR	24.25	0.000044	0.000045	0.000047	0.000055
5TH FLOOR	20.85	0.000053	0.000054	0.000056	0.000066
4TH FLOOR	17.45	0.000063	0.000064	0.000067	0.000079
3RD FLOOR	14.05	0.000075	0.000076	0.000080	0.000094
2ND FLOOR	10.65	0.000078	0.000079	0.000083	0.000097

1ST FLOOR	7.25	0.000085	0.000087	0.000091	0.000107
MEZZANINE FLOOR	3.85	0.000094	0.000096	0.000100	0.000118
GROUND FLOOR	0.45	0.000572	0.000580	0.000606	0.000714
LOWER GROUND FLOOR	-1.5	0.000301	0.000306	0.000319	0.000377
1ST BASEMENT	-4.99	4.12E-08	4.185E-08	4.37E-08	5.15E-08
2ND BASEMENT	-8.39	0	0	0	0
3RD BASEMENT	-11.79	0	0	0	0

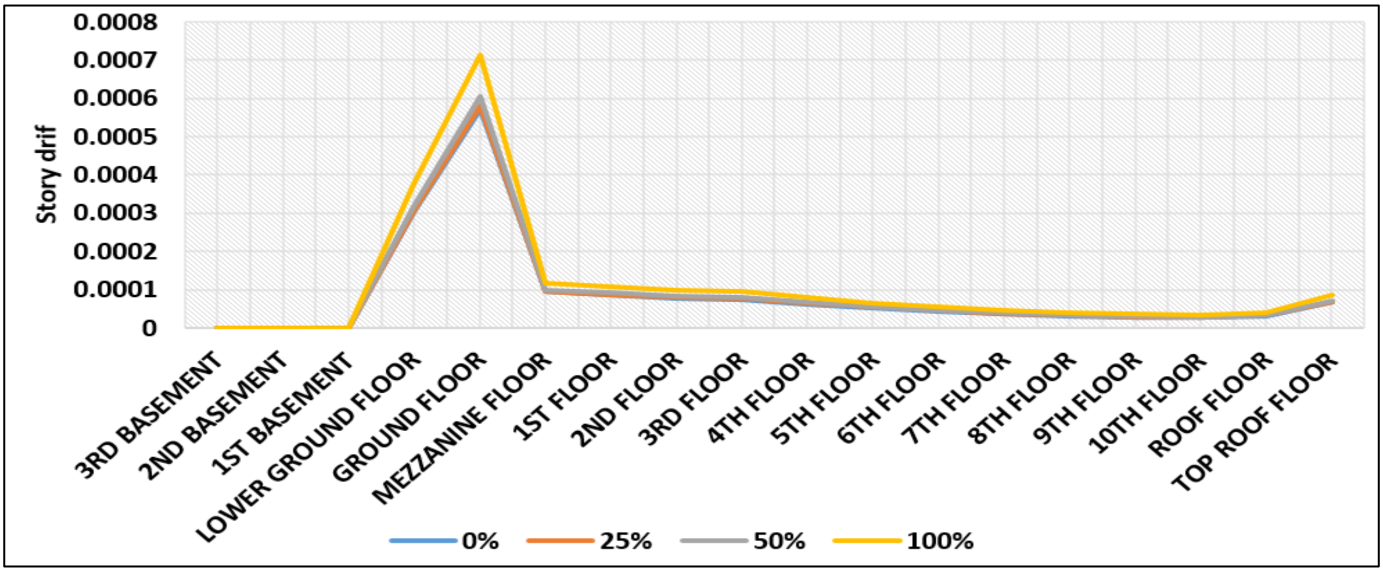

Fig 9 Lateral Story Drift in the X-Axis Direction

According to the data in Table 9, it has been determined that the story drift along the x-axis increased gradually with the height of the structure in all models. The smallest value was observed in the 3rd and 2nd basements, which was zero in all models.

In the 1st basement, it was also near zero because they are embedded in soil, which provides full lateral restraint. The highest value was observed at the ground floor for all RA replacement ratios. From the Mezzanine floor (elevation 3.85m) to the tenth floor (37.85m), the story drift decreased steadily from 0.000572 to 0.000027, followed by a smooth increase to 0.000032 for the roof floor and a sudden increase for the top roof floor, reaching 0.000068. This is because the ground floor is initially unrestrained, with a story above the firm foundation and soil supporting the basement walls.

Additionally, it carries the full lateral force produced by the upper stories, which causes higher movement compared to the lower basement stories. The upper stories, such as the roof floor and the top roof floor, are usually designed to be light, more flexible, and less confined; therefore, they undergo more lateral displacement.

In general, the increase in the aggregate replacement ratio expanded the story drift; a 100% replacement ratio presents the highest story drift compared to other percentages. For example, it was 0.000714 at the ground floor (0.45m elevation). The results are in agreement with the findings from [22].

To compare the ratio of the story drift of the different percentages, taking the highest drift ratio. The story drift of RA at 25%, 50%, and 100 percent of replacing ratio was higher than the corresponding setup of natural aggregate by 1.39 percent, 5.94 percent, and 24.82 percent in the x-direction. Also, in the y-direction, it was higher by 1.38%, 5.98%, and 25.05% for the same replacement ratios.

Table 10 Stories Drift in y-Direction.

Story	Elevation (m)	Natural	25% RA	50% RA	100% RA
TOP ROOF FLOOR	44.55	0.000185	0.000188	0.000196	0.000232
ROOF FLOOR	41.25	0.000326	0.000331	0.000346	0.000408
10TH FLOOR	37.85	0.000333	0.000338	0.000353	0.000416
9TH FLOOR	34.45	0.000333	0.000338	0.000353	0.000417
8TH FLOOR	31.05	0.000334	0.000339	0.000355	0.000419
7TH FLOOR	27.65	0.000338	0.000344	0.000359	0.000424
6TH FLOOR	24.25	0.000344	0.000349	0.000365	0.000431
5TH FLOOR	20.85	0.000350	0.000356	0.000372	0.000439
4TH FLOOR	17.45	0.000356	0.000362	0.000378	0.000446

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3RD FLOOR	14.05	0.000359	0.000365	0.000381	0.000450
2ND FLOOR	10.65	0.000355	0.000360	0.000376	0.000444
1ST FLOOR	7.25	0.000384	0.000390	0.000407	0.000480
MEZZANINE FLOOR	3.85	0.000207	0.000210	0.000220	0.000259
GROUND FLOOR	0.45	0.000435	0.000441	0.000461	0.000544
LOWER GROUND FLOOR	-1.5	0.000194	0.000197	0.000205	0.000242
1ST BASEMENT	-4.99	3.15E-07	3.195E-07	3.34E-07	3.93E-07
2ND BASEMENT	-8.39	0	0	0	0
3RD BASEMENT	-11.79	0	0	0	0

In the y-direction, the same trend in story drift was observed when increasing the replacement ratio for the same story. For natural aggregate, for the 3rd and 2nd basement floors, the drift was about zero and approximately zero in the 1st basement floor. Then the drift was increased to reach the peak of 0.000435 at the ground floor followed by steadily decrease to reach 0.000188 at the top floor roof. This trend was also observed in the other replacement ratio. In both directions, the story drift must be less than 0.0025, according to ASCE 7, and the values satisfied this limit.

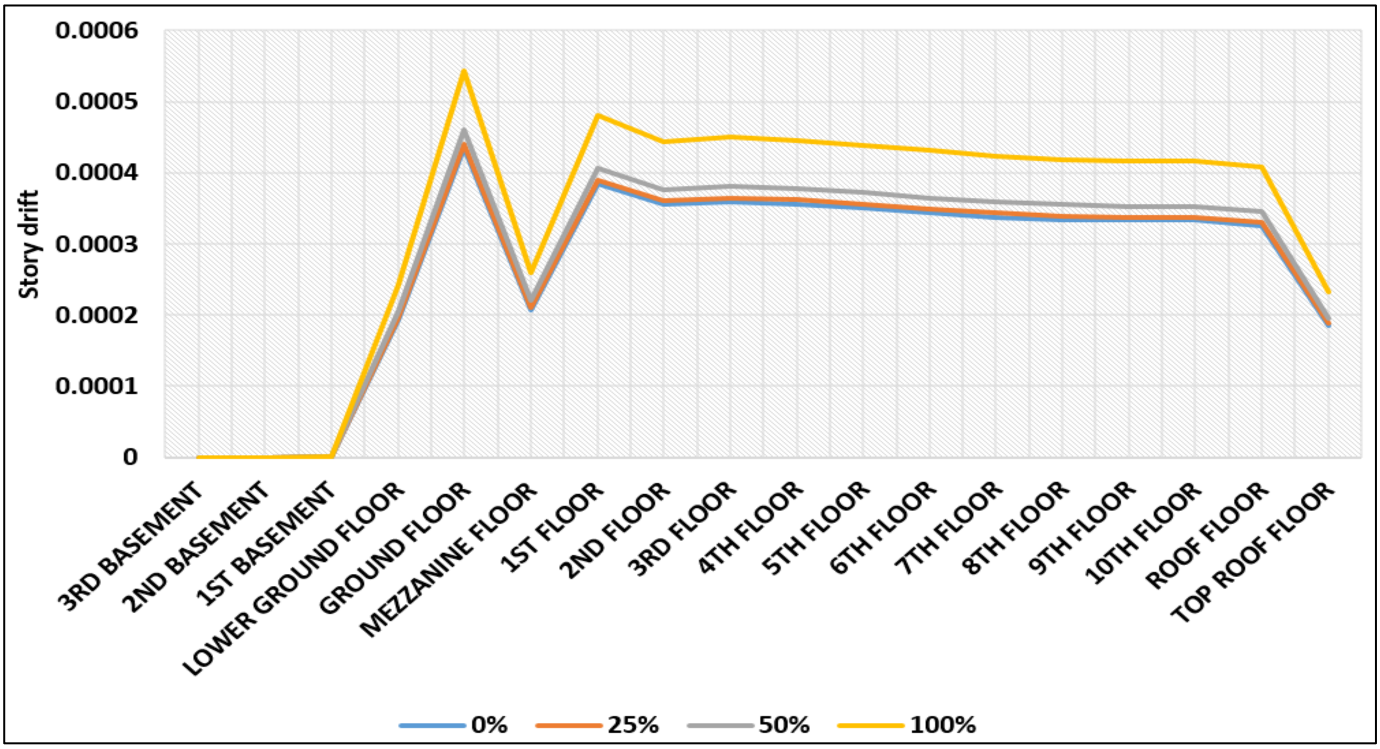

Fig 10 Sory Displacement in y-Direction

IV. CONCLUSION

This paper assesses the reinforced concrete high-rise building using various percentages of RA, as simulated in ETABS software, providing insights for sustainable structural design. Increasing the RA percentage caused an increase in stories lateral displacement because it has lower modulus of elasticity comparing with natural aggregate. Peak lateral story displacement of 17.426mm was reached when the replacement ratio was 100% and 13.919mm when use natural aggregate was used in the concrete mix. In the y-direction. The same trend was noticed in x-direction with lateral displacement of 2.928 and 2.339mm for 100% RA and natural aggregate, the lower displacement in x-direction although it was subjected to higher wind load is due to the confinement in the y-direction by the shear wall which resists the wind load from the x-direction. The displacement behaviour was nonlinear; it was increased by 1.72%, 6.06%, and 25.19% for 25%, 50%, and 100% replacement ratios, showing a peak at 100%.

In addition, the story drift ratio increased with the increase in the aggregate replacement ratio. The highest drift was 25.05% at the ground floor, when the replacement ratio was 100%, as it carried the lateral forces acting on the upper stories, resulting in higher movement compared to the other stories. In both directions and in all ETABS models, the story drift was less than 0.0025, which it is the story drift limit, according to ASCE 7.

The study results support the possibility of RA as a workable substitute of the natural aggregates when it comes to high-rise concrete buildings, and specifically in moderate amounts as well. Despite the fact that complete replacement

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can be the cause of significant values in lateral displacement and story drift, partial substitution, particularly at the level between 25 and 50 per cent, has shown hopeful ratio of structural integrity and environmental responsibility. These findings demonstrate the value of recycled materials in the design of structures not only on the basis of sustainability, but also on economic grounds. Further verification of the use of RCA in construction in the future needs to be done through studies that examine the durability of this kind of concrete under dynamic loads and extreme weather conditions.

To influence the scope of maintaining balance between the sustainability and structural performance in future design, a 25-50 percent level of replacement ratio should be implemented in the implementing of the RA into the concrete mix in implementation. Moreover, shear wall that offers a lateral bracing structure was suggested to counter the increased lateral movement experienced when the RA was used as the admixture in the concrete mix of a high-rise building. Lastly, the complete ratio of RAs replacement is advised to be utilised in non-critical components because replacement is not stringent.

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