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Research Article

Economical evaluation of reinforced concrete hospital construction cost using bottom ash and fly ash

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ABSTRACT

The use of waste materials in nature (e.g. fly ash, bottom ash) in the construction phase of buildings is of great importance both in terms of environmental pollution and the construction cost of the structures. Therefore, in this study, the effects of bottom ash and fly ash on the construction cost of reinforced concrete (RC) hospital buildings are investigated by considering experimental tests and 3D nonlinear analyzes. During the experiments, four different concrete series are created and fly ash and bottom ash are added to replace 0–5 mm grain size aggregates in the concrete mixture at different ratios. The RC beams created according to four different concrete series are subjected to experimental tests. Afterward, it is determined that the most critical mixing ratio for RC beams subjected to experimental tests is selected as 75% bottom ash ratio and fly ash. For the purpose Ankara Bilkent City Hospital is selected for 3D nonlinear seismic analyses and the hospital structure is subjected to 10 various earthquake analyses. This study showed that there was a noticeable decrease in the construction cost when the costs of the hospital structure were compared as a result of the earthquake analysis. Another important point is that the use of bottom ash and fly ash is thought to contribute to savings in the energy to be used for the storage of wastes by causing less electrical energy use in cement production, less greenhouse gas emissions, natural raw material consumption and nature pollution.

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1. Introduction

In many countries of the world, thermal power plants are built to produce energy, and millions of waste ash are generated from these thermal power plants every year. In these thermal power plants, coal is used for electricity generation and the coal ash generated as a result of production must be recycled in order not to harm the environment. However, the bottom ash and fly ash that is created in thermal power plants are thrown into nature and cause pollution of people's health and the environment. For this reason, recycling these waste materials is of great importance for the health of future generations. When coal burns in a thermal power plant, it leaves ash behind. Some falls to the bottom of the furnace, which is called bottom ash and some is carried upwards by the hot combustion gases of the furnace and held by the filter, which is called fly ash. The use of fly ash as recycled material can provide economic and environmental benefits (Epri 1998); using fly ash in building materials and concrete technology might solve the problems of industrial waste, environmental pollution, and destruction of thousands of acres of land and also offers the opportunity to create cost-effective new building materials (Zekić et al. 2014). Fly ash reduces CO2 emissions and is considered an environmentally friendly material because it can be used as a byproduct in Portland cement and various building materials and can be a cost-effective replacement for Portland cement in many markets (Rodriguez 2021). Tiles and bricks are made from fly ash emit 90% less carbon dioxide (Transparency Market Research 2019). When fly ash mixed with lime and water, it forms a compound similar to Portland cement and this makes fly ash suitable for the base material in blended cement,

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mosaic tiles, and hollow blocks (Rodriguez 2021). Fly ash can be partially used in concrete mixtures as a cement substitute and no need to grind and no need drying like trass. By using fly ash, less electrical energy will be used for cement production and so energy savings will be achieved. Since fly ash is a very thin material, it increases the workability of concrete as well (Arioğlu and Manzak 1992). Since the use of fly ash in cement ensures less use of cement clinker, it has environmental benefits such as less greenhouse gas emissions, less consumption of natural raw materials, less pollution of nature, energy saving used in the storage of waste, as well as technical benefits such as high-strength concrete and low hydration temperature (Cement Research and Application Center).

One of the most common uses of fly ash is plain Portland cement concrete (PCC) coating. Road construction projects using PCC can use large amounts of concrete, and the additive of fly ash provides significant economic benefits. More than 50% of concrete placed in the USA contains fly ash (Rodriguez 2021). The Ministry of Environment and Urbanization of Türkiye states that in accordance with the general technical specification for construction, there should be a minimum of 250 kg/m^3 cement and 50 kg/m^3 fly ash to be used in the roller compacted concrete mixture. Additionally, according to the general technical specifications for reinforced concrete works, it is recommended that mineral additives such as fly ash should not exceed 30% of the cement amount in order not to deteriorate the permeability property of concrete (Directorate of High Technics Board 2018).

Bricks composed of fly ash can be produced in various strengths and sizes, and be found in building walls etc. Besides their traditional uses, bricks composed of fly ash can also be used for the construction of various infrastructure projects such as roads and sidewalks, dams and bridges (Attarde et al. 2014). In addition, it can be used in concrete additives, fine aggregate, coarse aggregate, light aggregate, clay additive, brick binder material, aerated concrete blocks, concrete panels, concrete, glass, wood and ceramics (Güler et al. 2005; Aruntaş 2006; Transparency Market Research 2019).

According to the data obtained from the Provincial Environmental Status Reports prepared by the Provincial Directorates of Environment and Urbanization, the total amount of coal used in thermal power plants in 2015 was around 60,666,000 tons, and the fly ash and bottom ash produced was approximately 17,710,000 tons (Republic of Türkiye Ministry of Environment and Urbanisation 2016). According to another statistic, the results of Thermal Power Plant Water, Wastewater and Waste Statistics Survey in 2018, 26.1 Million tons of waste was generated in 55 active thermal power plants with an installed power of 100 megawatts (MW) and above, 87.5% of which was sent to ash mountain or ash dam, and 12.4% was sent to licensed waste processing facilities and used for backfilling of mines, while 0.1% was disposed of by other methods (TURKSTAT 2019).

There are very few studies in the literature about the recycling of fly ash and bottom ash and their effects on construction costs such as Chindaprasirt et al. (2009), Rafieizonooz et al. (2016), Canpolat et al. (2004), Andrade et al. (2007, 2009), Siddique et al. (2012), Abdulmatin et al. (2018), Boonserm et al. (2012), Kim and Lee (2011), Garcia-Lodeiro et al. (2016), Wongsa et al. (2016), Jurič et al. (2006), Albitar et al. (2015), Aruntaş (2006), Ashish et al. (2018), Baspinar et al. (2014), Cavusoglu et al. (2021), Dinelli et al. (1996), Verma et al. (2016, 2019), Wang et al. (2016), Wu et al. (2014), and Yost et al. (2013). In these studies, the effects of fly ash material on the structural behavior of the structures have been investigated and it has been concluded that fly ash material has great effects on both the structural and cost of the structures.

As seen from these studies, very few investigators have examined the effects of various fly ash and coal bottom ash ratios on the construction cost of structures in the past. Besides, there are very few studies about the effects of various fly ash and coal bottom ash ratios on the 3D seismic behavior of hospital structural elements (beams, columns) in the literature. For this reason, this study is of great importance to overcome these gaps in the literature.

2. Scope of the Study

In this study, the effects of different fly ash and bottom ash ratios on the construction cost of structures are investigated in detail. For this aim, firstly, four various concrete beams with different fly ash and bottom ash ratios are created in the laboratory (Karalar 2020). After pure concrete is generated, fly ash and bottom ash are used instead of aggregate in pure concrete. The fly ash ratios used in pure concrete are 25%, 50%. Moreover, the bottom ash ratio utilized in pure concrete is 75%. Then, these beams are subjected to a bending test. The most critical beam (concrete with 75% coal bottom ash) is taken as a reference and the properties of this reference concrete material are used for structural elements of a hospital to examine the effects of coal bottom ash ratios on the construction cost of RC hospital structures. For this aim, the existing hospital building is modeled with the mechanical properties of the 75% bottom ash substitution and the carrier system has been reanalyzed, except for the foundation system. Then, earthquake analysis is performed and it is observed that the hospital structure is not damaged in the earthquake as dimensions of the columns and beams in the hospital structure used coal bottom ash added to the concrete are reduced. And then, the cost has been compared between concrete with 75% bottom ash substitution and without bottom ash in the current design. From this result, it is concluded that as concrete with 75% coal bottom ash is used in hospital structures, there will be a significant reduction in the cost of hospital structures and this recycling will make a significant contribution to the country's economy.

3. Preparation of the Reinforced Concrete Beams

In Zonguldak-Türkiye, coal is produced since the 1900s and this produced coal is sent to both other provinces and countries. For this reason, a coal-fired thermal power plant (Çates) was established in Zonguldak to turn coal into energy. The waste coal bottom ash produced in this coal-fired thermal power plant is released to nature every day and causes great damage to nature. Therefore, recycling of this coal bottom ash is of great importance both for Türkiye's economy and the health of people living located in the Zonguldak. In this study, the contribution of the addition of coal bottom ash, which is waste in nature, to the construction cost of hospital structures is investigated both experimentally and numerically. Experimentally, the concrete material is prepared in the laboratory and 75% coal bottom ash ratio is added instead of aggregate in the prepared concrete materials. Besides, 25% and 50% coal fly ash ratios are added instead of aggregate in the concrete materials. As a result of this experiment, 75% bottom ash ratio is determined as the most critical ash ratio. Details of the concrete samples prepared in the laboratory are presented in Table 1. As can be seen from Table 1, sample 1 represents pure concrete and other samples represent additive concretes. Coal bottom ash has been used in the concrete mix to replace aggregates of 0-5 mm grain size. Details of the materials used in 4 different concrete beams are presented in Table 2. Components in the cement and weight per unit of components are presented in Table 3.

Table 1. Concrete samples for various bottom ash ratios (Karalar 2020).

Sample number	Statement
1	Pure concrete
2	%25 fly ash
3	%50 fly ash
4	%75 bottom ash

Table 2. Components in the concrete samples and weight per unit of components (Karalar 2020).

Components	Weight per unit of volume (%)
Portland Cement Clinker	45 – 64
Limestone	0 – 5
Gypsum	3 – 6
Calcium Oxide	0 – 5
Magnesium Oxide	0 – 5
Natural Pozzolan	36 – 55

Table 3. Components in the cement and weight per unit of components (Karalar 2020).

Material	Reference (kg)	75% Bottom ash (kg)	25% Fly ash (kg)	50% Fly ash (kg)
Cement	9.0	9.0	6,75	4,500
Water	4.77	4.77	4.77	4.77
Fly ash	0.0	0.0	1,294	2,588
Bottom ash	0.0	11,312	11,312	11,312
0-5 mm aggregate	23.1450	5.7854	5.7854	5.7854
5-15 mm aggregate	12.7320	12.7320	12.7320	12.7320
15-25 mm aggregate	21.9900	21.9900	21.9900	21.9900
Chemical admixture	0.1200	0.1200	0.1200	0.1200
Unit weight of concrete	71.7570	65.7107	64,755	63,799

For the reinforced concrete samples, bottom ash is obtained from Zonguldak coal-fired thermal power plant and added to the concrete materials. The capacity of this coal-fired thermal power plant is 2x150 MW. Approximately 1.500.000 tons of coal is burned annually in this factory. At the end of this burning process, tons of ash are formed annually. 4 different concrete sample mixes are mixed in the concrete mixer and the concrete consistency is adjusted. Concrete samples were placed in cube molds in the laboratory and kept in water for 28 days (Fig. 1).

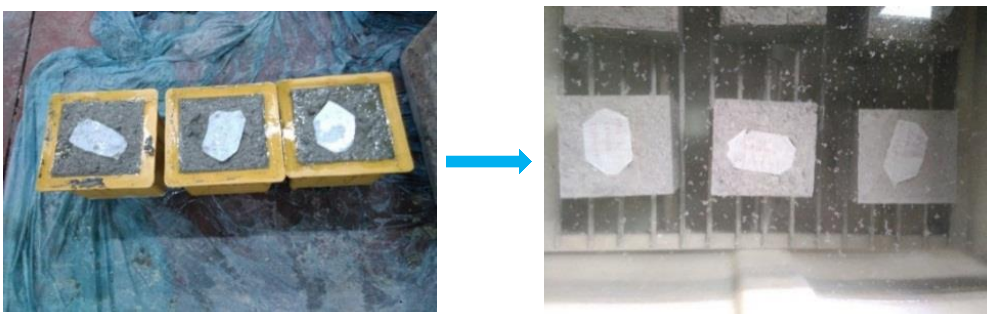

Fig. 1. Preparation of concrete samples in the laboratory (Karalar 2020).

Fig. 2 shows that how concrete beams and beam molds are prepared in the laboratory. 4 different reinforced concrete beam molds are prepared in a private laboratory. The dimensions of the 4 different beam molds are equal and the beam mold dimensions are 300 x 400 x 2000 mm. Total of 10 different stirrups are used in concrete beams and the distances between stirrups are 200 mm. Besides, the diameter of stirrups is 8 mm. 2 compression reinforcements are placed on the concrete beams to ensure stirrup connections. These compression reinforcement bars have a diameter of 12 mm. In addition, 3 tension reinforcements are placed at the bottom of the beam molds and the diameter of these tension bars is 12 mm. After a total of 4 different beams are prepared in the laboratory, a total of 28 days are waited for the concrete to reach the desired hardness, and after 28 days, the beam molds are removed (Karalar 2020).

Fig. 2. Preparation of molds for concrete beams (Karalar 2020).

4. Experimental Test Set-up and Results

Used devices for crack and flexure analyses of concrete beams are shown in Fig.3. Four different RCBs prepared in the special laboratory are subjected to flexure and crack tests. Flexure and crack test results for all beams are presented in Fig. 3. According to Fig. 3, the maximum crack width for pure concrete is 3.17 cm. Besides, the maximum distance between the vertical cracks was 15 cm in the reference concrete beam. In Fig. 3, the flexure and crack test results of the beam prepared by adding 75% coal bottom ash into concrete instead of aggregate are presented. According to Fig. 3, the maximum crack width is 2.82 cm and the maximum crack length is 39 cm. From this result, it is seen that when coal bottom ash is added to the concrete, the crack width and crack length decrease. Furthermore, the maximum crack width on the beam is 3.16 cm and the maximum crack length is 32 cm. In Fig. 3, test results of the beam prepared by adding 50% coal fly ash to the aggregate in the concrete are presented. If 50% of coal fly ash is added instead of aggregate in the concrete inside the beam, the maximum crack width is 3.38 cm and the maximum crack length is 24 cm. It is clear from these results that the most critical threshold value for four different ash ratios used instead of aggregate in concrete is 75% coal bottom ash ratio. From this result, it is concluded that using 75% coal bottom ash ratio in reinforced concrete structures may cause less damage in the RC structures (Karalar 2020).

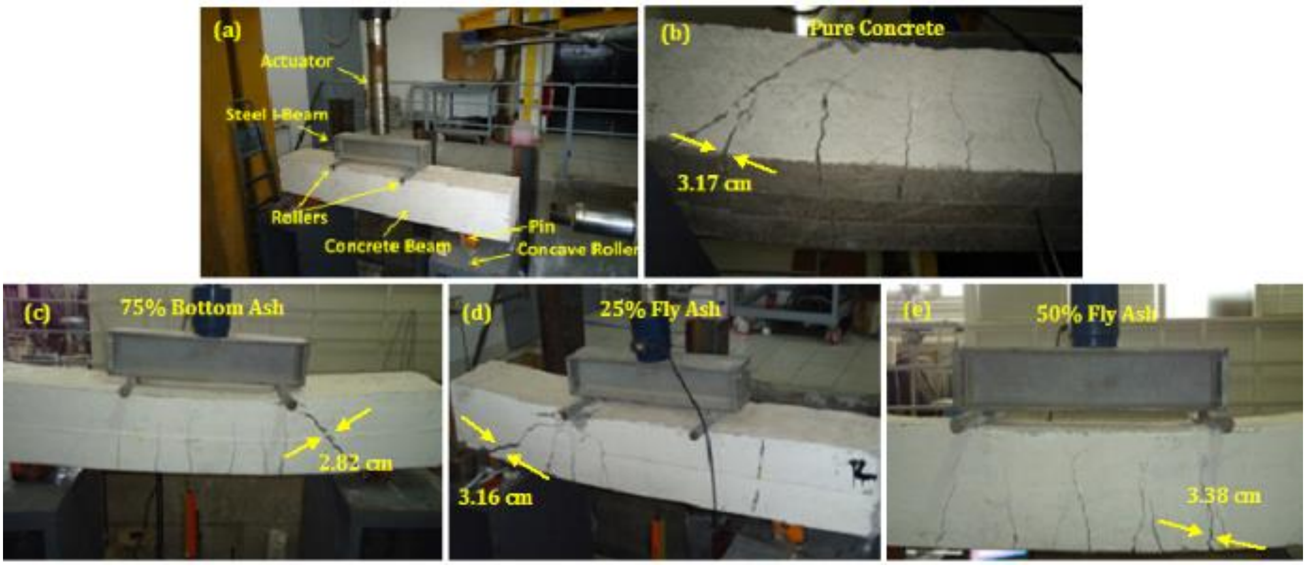

Fig. 3. Crack and flexure behavior of reference concrete beam: (a) Static testing apparatus; (b)Pure concrete; (c) 75% Bottom ash; (d) 25% Fly ash; (e) 50% Fly ash (Karalar 2020).

5. 3D Earthquake Analysis Results

This section, it is aimed to investigate the effects of the 75% bottom ash ratio in the concrete on the 3D seismic behavior of hospital buildings. For this aim, a 10 story hospital structure is selected for 3D modeling and this building is modeled as 3D using SAP2000 software based on the finite element method (Carhoglu 2022). The hospital building was built in Ankara. The general view of Ankara Bilkent city hospital used in 3D analyzes is presented in Fig. 4. 3D model of the building is shown in Fig. 5.

Fig. 4. General view of Ankara Bilkent city hospital (URL-1 2022).

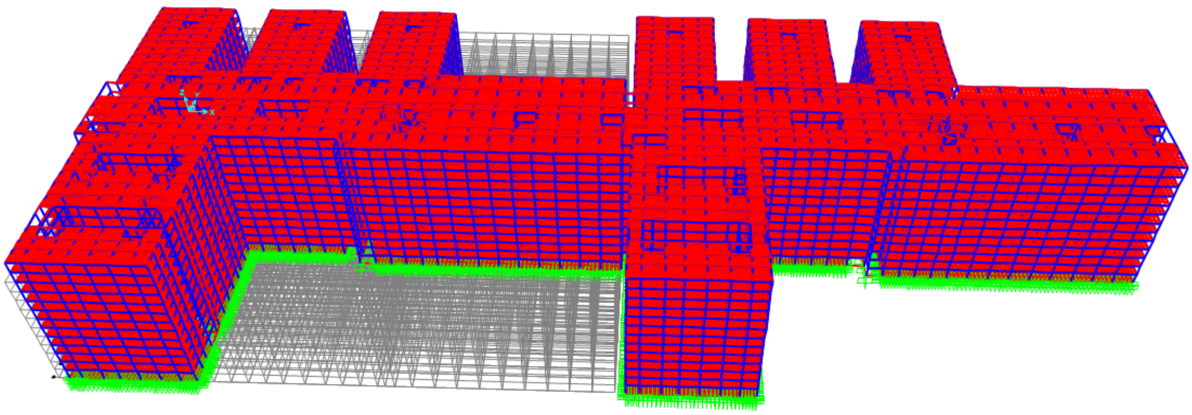

Fig. 5. View of 3D model of the hospital building.

Table 4. Mechanical properties of various earthquakes.

Earthquake record station	d (km)	PGA	PGV	Ap/Vp	TPV	TP
1999 Chi-Chi Earthquake 1	17.8	0.17	59	2.83	6.5	6.0
1999 Chi-Chi Earthquake 2	18.1	0.25	46	5.33	1.4	1.3
1979 Imperial Valley Earthquake 1	0.5	0.30	91	3.23	3.0	3.1
1979 Imperial Valley Earthquake 2	0.6	0.46	109	4.14	3.2	3.8
1979 Imperial Valley Earthquake 3	1.0	0.38	91	4.10	3.4	3.9
1995 Kobe Earthquake	0.6	0.60	74	7.95	0.8	1.4
1989 Loma Prieta Earthquake	5.1	0.48	45	10.46	0.8	0.7
1986 North Palm Spring Earthquake	8.2	0.59	73	7.93	1.1	1.4
1994 Northridge Earthquake 1	7.1	0.45	93	4.75	2.0	3.2
1994 Northridge Earthquake 2	7.1	0.33	67	4.83	1.8	1.9

3D earthquake analysis results are shown in Table 5. As Table 5 is examined, the earthquake analysis results for the current situation of the structure and the earthquake analysis results for the coal bottom ash added situation of the RC structure are presented separately. 3D earthquake analyses are performed under 10 different earthquakes. According to 10 different earthquake analysis results, no damage is obtained in the structural elements for the current situation of the building. From this result, it is concluded that the existing bearing columns and beams are sized appropriately for these earthquakes. Besides, provided that the dimensions of the existing bearing elements of the structure remain constant, it has been observed that if 75% of the coal bottom ash is added to the aggregate in the bearing elements of the structure, no damage will occur for 10 different earthquakes. When the size of the columns and beams is reduced by 10% ratio for the structure with coal bottom ash, there is no damage to the building for 10 different earthquakes. No damage is observed in the structure for 10 different earthquakes in the case of reducing the dimensions of the carrier elements by 20%, 30%, 40% ratios for the structure with coal bottom ash. However, if the dimensions of the bearing elements for the coal bottom ash added structure is reduced by 50% ratio, the structure is damaged for the 1999 Chi-Chi earthquake, 1989 Loma Prieta earthquake, 1986 North Palm earthquake, 1994 Northridge earthquake. In this case, it is concluded that the reduction ratio that should be taken as reference is 40% ratio. From this result, it is concluded that if 75% ratio of coal bottom ash is used instead of aggregate in the structures, the carrying elements of the structure can be reduced by 40% ratio, and if the carrier elements are reduced by 40% ratio, the structure may resist earthquakes. It is understood from this result that if 75% ratio of coal bottom ash waste material is used in concrete material of RC structures, it will cause a significant decrease in the cost of the building (Table 5).

Table 5. Earthquake analysis results for current situation and coal bottom ash added situation.

Earthquake	Current situation of structure	Reduction ratio for structural elements (beams and columns)					
		10%	20%	30%	40%	50%	60%
1999 Chi-Chi Earthquake 1	+	+	+	+	+	+	-
1999 Chi-Chi Earthquake 2	+	+	+	+	+	-	-
1979 Imperial Valley Earthquake 1	+	+	+	+	+	-	-
1979 Imperial Valley Earthquake 2	+	+	+	+	+	-	-
1979 Imperial Valley Earthquake 3	+	+	+	+	+	+	-
1995 Kobe Earthquake	+	+	+	+	+	+	-
1989 Loma Prieta Earthquake	+	+	+	+	+	+	-
1986 North Palm Spring Earthquake	+	+	+	+	+	-	-
1994 Northridge Earthquake 1	+	+	+	+	+	+	-
1994 Northridge Earthquake 2	+	+	+	+	+	-	-

6. Effects of the Construction Cost

For cost comparisons shown in this section of the study, the analyses, unit prices and transport formulas published by the Ministry of Environment, Urbanization and Climate Change of Türkiye are used. Sand, crushed stone and cement are brought from the closest mine and factory to the construction site at a distance of 16 km and 160 km shown in Table 6 and 7. The bottom ash and fly ash is brought from the Catalagzi Thermal Power Plant at a distance of 70 km shown in Table 8, which is also assumed that it will be taken free of charge except the transportation fee. Tables 9 and 10 show the approximate unit costs of one cubic meter of reference concrete and one cubic meter of concrete prepared using bottom ash and fly ash, respectively. The cost comparison between bottom ash and fly ash used in cement mortar and reference concrete for the current design can be seen in Table 11 and the cost comparison between the current design and the more economic design can be seen in Table 12. The density of sand or crushed stone is taken into account in calculations as 1.6 tons/m^3 to convert ton to m^3.

Unit prices of plant-mixed concrete in Tables 9 and 10 are calculated using the construction unit prices and analyses of the Ministry of Environment and Urbanization of Türkiye. The calculated unit prices show approximate market prices and may vary.

It has been seen in the laboratory experiments that when bottom ash and fly ash with 150 kg cement is used in cement mortal, much more compressive strength, and much more flexural and tensile strength than the reference concrete with 300 kg cement in one cubic meter are obtained. Also, of the unit weight is approximately 10 % less than the reference concrete.

Firstly, in this case it is considered no change in the sizes of load-bearing structural elements in the current design shown in Table 11, it is compared the structure costs when using reference concrete or bottom ash and fly ash in cement mortal. It is seen that the structure cost when bottom ash and fly ash used in the concrete is approximately 10% less.

Table 6. Transportation of 1 m³ of sand or crushed stone to the construction site.

Name of analysis: Sand or crushed stone transportation (m³)					
Item/group #	Entries	Metric	Quantity	Unit price	Sum ($)
19.100.2495	F = A x K x (0.0007 x M+0.01) x G				1.97
A	Difficulty coefficient		1.00		
G	Density of sand and crushed stone	ton/m³	1.60		
10.110.1003	K: Motor vehicle carriage coefficient	$	58.10		
M	Transportation distance	km	16.00		
15.100.1002*	Loading, unloading and storing of 1 m³ of material.	m³	0.80	0.517	0.41
*If the material on the construction site is available, 80% of the transportation cost will be paid.					
			Transportation and labor cost		2.38
Note: Density of cement is not taken into account in the calculation because no conversion is needed.					

Table 7. Transportation of 1 ton of cement to the construction site.

Name of analysis: Cement transportation (ton)					
Item/group #	Entries	Metric	Quantity	Unit price	Sum ($)
19.100.2495	F = A x K x (0.0007 x M+0.01)				7.09
A	Difficulty coefficient		1.00		
10.110.1003	K: Motor vehicle carriage coefficient	$	58.10		
M	Transportation distance	km	160.00		
15.100.1001*	Loading, unloading and stowing of 1 ton of cement	ton	0.50	2.797	1.40
* Loading fee is deducted for ex-factory materials * If the loading is done at the factory, half of the unit price will be deducted.					
			Transportation and labor cost		8.49
Note: Bottom ash and fly ash is brought from Catalagzi Thermal Power Plant and density of them is not taken into account in the calculation because no conversion is needed.					

Table 8. Transportation of 1 ton of bottom ash or fly ash to the construction site.

Name of analysis: Bottom ash or fly ash transportation (ton)					
Item/group #	Entries	Metric	Quantity	Unit price	Sum ($)
19.100.2495	F = A x K x (0.0007 x M+0.01)				3.43
A	Difficulty coefficient		1.00		
10.110.1003	K: Motor vehicle carriage coefficient	$	58.10		
M	Transportation distance	km	70.00		
15.100.1002*	Loading, unloading and storing of 1 m³ of material.	m³	0.80	0.517	0.41
*If the material on the construction site is available, 80% of the transportation cost will be paid.					
			Transportation and labor cost		3.84

Table 9. Unit price of 1 m³ of plant-mixed reference concrete including transportation.

Item #	Definition	Metric	Quantity	Unit price	Sum ($)
	Material (cement mortar):				
10.130.1026	Sand	m³	0.482	4.15	2.00
	Sand transportation	m³	0.482	2.38	1.15
10.130.1029	Crushed stone (up to 32 mm)	m³	0.723	6.17	4.46
	Crushed stone transportation	m³	0.723	2.38	1.72
10.130.1204	Portland cement (bulk)	ton	0.300	35.78	10.73
	Portland cement transportation	ton	0.300	8.49	2.55
10.130.9991	Water	m³	0.159	1.23	0.20
10.300.2004	Plasticizing-air entraining mortar fluid admixture on the job	kg	4.000	0.70	2.80
	Labor:				
	Pumping and pouring:				
19.100.1059	Hourly rate of an automatic concrete plant (1000 L capacity, 50 m³/hour)	h	0.0200	7.51	0.15
10.100.1015	Concrete master	h	0.3000	3.06	0.92
10.100.1063	Expert laborer	h	0.3000	2.39	0.72
10.100.1051	Driver	h	0.6000	3.12	1.87
10.100.1055	Machine operator	h	0.6000	3.59	2.16
10.100.1057	Assistant operator	h	0.6000	2.95	1.77
10.160.1026	Diesel fuel	kg	1.4250	0.89	1.27
10.160.1030	Electric power	kWh	8.7500	0.12	1.01
10.100.1062	Unskilled construction worker	h	5.0000	2.24	11.19
	Compacting and protecting:				
19.100.1033	Hourly rate of a concrete vibrator	h	0.3125	4.23	1.32
10.130.9991	Water for curing	m³	0.5000	1.23	0.62
10.100.1015	Concrete master	h	0.9375	3.06	2.87
	Sampling and Laboratory Tests:				
10.100.1060	Foreman	h	0.3125	4.49	1.40
10.100.1062	Unskilled construction worker	h	0.3125	2.24	0.70
				Material and labor cost	53.58
				10% contractor's profit and 15% overheads	13.39
				Price per m³	66.97

In the another case it is considered the mechanical properties of the bottom ash and fly ash mix and it is designed the structure more economically. It is seen in Table 12 that the cost difference increases significantly (approximately %25 less).

7. Conclusions

In this study, it has been investigated whether bottom ash and fly ash thrown into nature as waste material from a thermal power plant can be used in reinforced concrete structures and if so, what its effect is on construction costs. In the current design (built structure), the cost of concrete used in the Load-bearing structural is calculated as $3,614,078, and the cost of concrete with bottom ash and fly ash mix in concrete is $3,230,033, so the difference is $384,045 which will be approximately 10% less than the built structure. If the building had been designed considering the mechanical properties of the bottom ash and fly ash, then the cost difference would have been $923,939 (3,614,078-2,690,134), which is approximately 25% less. This is because the increase in strength allows the sizes of load carrying elements to be designed more economically. The fly ash market is estimated to generate 11,371 Million US Dollars in revenue in the United States by 2026 (Transparency Market Research 2019). Türkiye produced 95 Million cubic meters of ready-mixed concrete in 2020 according to Turkish Ready-Mixed Concrete Association (2020) and according to Türkiye Statistical Institute in the year of 2018 data, 22,861,242 cubic meters of coal waste (fly ash, bottom ash and boiler slag) from power plants was disposed (TURKSTAT 2019). If bottom ash and fly ash had been used in approximately ten Million cubic meters of concrete, 4.634 Million tons of bottom and fly ash (10 Million * 0.4634 ton/m3) would have been used and the cost difference in concrete would have been $56.9 Million US Dollars (10 Million * $5.69). An-other important point is that, by using bottom ash and fly ash, less electrical energy will be used for cement production and energy consumption will be reduced considerably. In addition, it has environmental benefits such as less greenhouse gas emissions, less consumption of natural raw materials, less pollution of nature, energy saving used in the storage of waste and reduction the disposal costs.

Table 10. Unit price of 1 m^3 of plant-mixed concrete with bottom ash and fly ash including transportation.

Item #	Definition	Metric	Quantity	Unit price	Sum ($)
	Material (cement mortar):				
10.130.1026	Sand	m^3	0.121	4.15	0.52
	Sand transportation	m^3	0.121	2.38	0.30
10.130.1029	Crushed stone (up to 32 mm)	m^3	0.723	6.17	4.46
	Crushed stone transportation	m^3	0.723	2.38	1.72
10.130.1204	Portland cement (bulk)	ton	0.150	35.78	6.71
	Portland cement transportation	ton	0.150	8.49	1.59
N/A	Fly ash	ton	0.0863	0.00	0.00
	Fly ash transportation	ton	0.0863	3.84	0.72
N/A	Bottom ash	ton	0.3771	0.00	0.00
	Bottom ash transportation	ton	0.3771	4.80	0.90
10.130.9991	Water	m^3	0.1590	1.23	0.20
10.300.2004	Plasticizing-air entraining mortar fluid admixture on the job	kg	4.000	0.70	2.80
	Labor:				
	Pumping and pouring:				
19.100.1059	Hourly rate of an automatic concrete plant (1000 L capacity, 50 m^3/hour)	h	0.0200	7.51	0.15
10.100.1015	Concrete master	h	0.3000	3.06	0.92
10.100.1063	Expert laborer	h	0.3000	2.39	0.72
10.100.1051	Driver	h	0.6000	3.12	1.87
10.100.1055	Machine operator	h	0.6000	3.59	2.16
10.100.1057	Assistant operator	h	0.6000	2.95	1.77
10.160.1026	Diesel fuel	kg	1.4250	0.89	1.27
10.160.1030	Electric power	kWh	8.7500	0.12	1.01
10.100.1062	Unskilled construction worker	h	5.0000	2.24	11.19
	Compacting and protecting:				
19.100.1033	Hourly rate of a concrete vibrator	h	0.3125	4.23	1.32
10.130.9991	Water for curing	m^3	0.5000	1.23	0.62
10.100.1015	Concrete master	h	0.9375	3.06	2.87
	Sampling and Laboratory Tests:				
10.100.1060	Foreman	h	0.3125	4.49	1.40
10.100.1062	Unskilled construction worker	h	0.3125	2.24	0.70
				Material and labor cost	47.89
				10% contractor's profit and 15% overheads	11.97
				Price per m^3	59.86

Table 11. Cost comparison between bottom ash and fly ash used in cement mortar and reference concrete for the current design.

Load-bearing structural elements	Concrete volume	Reference concrete	Concrete with bottom ash & fly ash
	m^3	($/$m^3$)	($/$m^3$)
Column	5,859.899	$66.97	$59.86
Beam	8,671.321		
Slab	14,855.303		
Foundation	24,576.039		
Total	53,962.562	$3,614,078	$3,230,033
Difference		$384,045	

Table 12. Cost comparison between the current design and the more economic design.

Load-bearing structural elements	Current design		New design	
	Concrete volume	Reference concrete	Concrete volume	Concrete with bottom ash & fly ash
	m^3	($/$m^3$)	m^3	($/$m^3$)
Column	5,859.899	$66.97	4,394.776	$59.86
Beam	8,671.321		7,983.826	
Slab	14,855.303		13,488.680	
Foundation	24,576.039		19,075.541	
Total	53,962.562	$3,614,078	44,942.824	$2,690,134
Difference			$923,939	

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