SIMPLE BEAM DESIGN, COST & CO_2 ASSESSMENT FOR GREEN CONCRETE CONTAINING HIGH VOLUME OF RECYCLED MATERIALS

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ABSTRACT**:** Now it is known the usage of different kind of by-products and recycled materials in the concrete industry, most of them showing that can be possible decrease the amount of carbon dioxide emissions and the consumption of virgin materials, and at the same time to have a concrete with good mechanical performance. In this paper were evaluated the mechanical performance, cost and CO_2 emissions for different types of concrete. For these cases were replaced cement with fly ash and normal aggregate with recycled aggregate in order to see the water-binder ratio, aggregate type and fly ash effect; then were evaluated the strength, air permeability, carbon dioxide emissions and volume of recycled material for every series. After that a structural design for a simple supported beam was calculated based upon the results obtained from the experimental tests for all the series. For the structural design were considered different cases taking into account common parameters for every case like load, length, section, reinforcement, carbon dioxide emissions or cost and finally evaluating and comparing them. It was found that it is possible to utilize green concrete with high volume of recycled materials, since it has a good balance between the mechanical performance, cost and CO_2 emissions compared with normal concrete.

KEYWORDS: green concrete, CO_2 emissions, beam design.

1. INTRODUCTION

It is well known the increasing necessity of taking care of our planet in order to preserve it for the future generations which has been commonly understood as sustainable development. On this regard the concrete industry can play an important role. Carbon dioxide (CO_2) is the primary GHG contributing to climate change, and some researchers estimate that the manufacture of Portland cement is responsible for roughly 7% of the world's total emissions. The consumption of natural resources like aggregate, water, and sand is another important item, due to the limited resources.

In order to reduce the carbon dioxide emissions and preserve raw materials, we are developing concrete which replaces cement with fly ash, and normal aggregate with recycled aggregate. Some researches evaluating this kind of materials have been developed showing that is possible to produce still concrete having good mechanical performance; with the purpose of reinforcing this and show also that the combination of these materials has good results we cast different concrete series with different proportions, evaluating their strength and air permeability and compared them with a control series which is considered to have the normal proportions of common concrete used for commons constructions in Japan. Then a simple supported beam design was conducted and the results analyzed to evidence that this kind of concrete containing high volume of recycled materials is possible to use in the real construction industry, even having some extra benefits as it will be shown.

2. CONCRETE MIXES

2.1 Mix proportions

The concrete mixes used for the beam design are given in Table 1, Water (W), normal Portland cement (C), type-II fly ash (FA), river sand (S), normal aggregates (NG), and grade-L recycled aggregates (RG) were used. Different factor were compared among series such as fly ash content effect (none vs. 50%), the effect of aggregate type (normal vs. recycled), and the effect of combining fly ash and recycled aggregates. The series control is the one chosen as normal concrete with common mix proportions and water-binder ratio 0.5, for all other series the water-binder ratio is 0.3.

Table 1 Mix proportions

Series	kg/m^3					
	W	C	FA	S	NA	RA
Control	171	342	-	746	1015	-
NB-NA	165	550	-	624	1009	-
NB-RA	165	550	-	624	-	905
NB-NA-FA50	165	275	275	590	955	-
NB-RA-FA50	165	275	275	590	-	856

2.2 Mechanical properties

The properties of concrete mixes are given in Figure 1. The compressive strength and air permeability values were taken at 28 days from casting under water curing conditions. Concrete with fly ash develops more strength time (i.e. at 56 or 91 days) than other series, however for this calculation were used 28 days results for being more traditional in current construction industry, however it is known that concrete with fly ash develops more strength in time than other concrete, improving its mechanical performance.

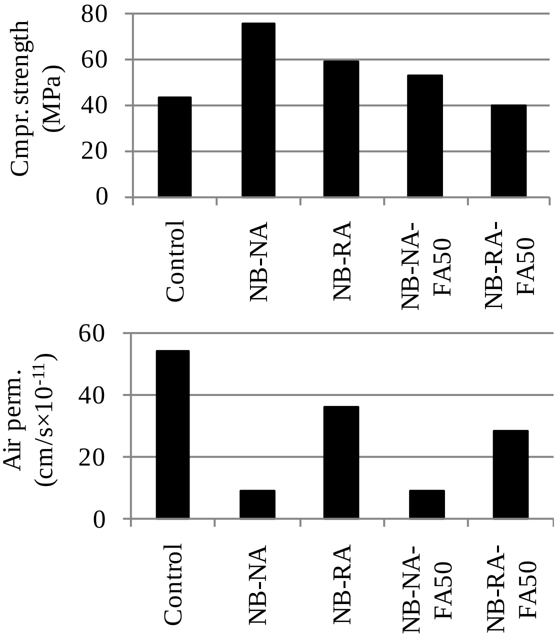


Figure 1 Mechanical properties of concrete mixes; top: compressive strength; bottom: air permeability

The series with highest compressive strength is NB-NA, the series with fly ash and recycled aggregate has a compressive strength slightly lower but still close to the control series. From the air permeability results it can be seen that all series shows better performance than the control series.

2.3 Environmental Impact

For the environmental impact were considered the carbon dioxide emissions (CO_2) and volume of recycled materials used to replace the virgin ones as the percentage per cubic meter. The CO_2 emissions for each mix were determined from the mix proportions and the emissions per component materials given by Japan Society of Civil Engineers, in Table 2. Finally, the recycled materials volume was calculated as the percent volume per cubic meter occupied by fly ash and/or recycled aggregate. The values per series are shown in Figure 2.

Table 2 CO_2 emissions values

Material	CO_2 emission (kg CO_2/ton)
Portland Cement	766.5
Fly ash	19.6
Natural river sand	3.7
Normal aggregates	2.9
Recycled aggregates	3.1

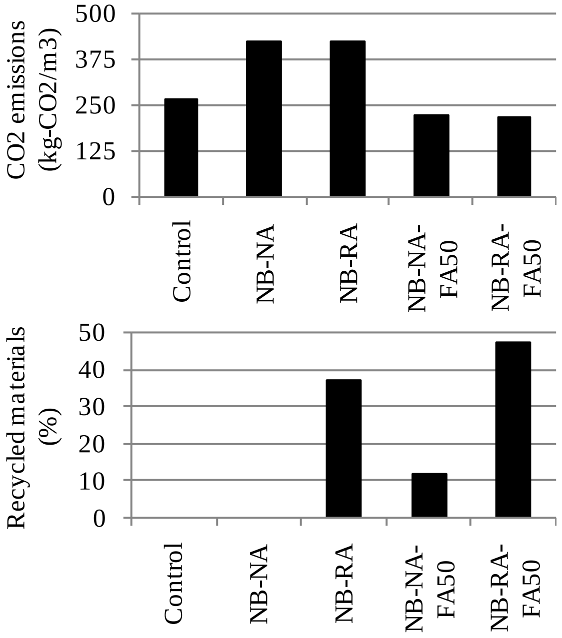


Figure 2 Environmental impact of concrete mixes; top: CO_2 emissions: bottom: volume of recycled materials

The series with highest CO_2 are those for non-fly ash series, this is due to their large amount of cement which is the principal contributor among the concrete materials; and the series with highest percentage of recycled materials are those with recycled aggregate due to the high volume occupied by coarse aggregate when making concrete which occupies a great volume of concrete, also fly ash normal aggregate series has some percentage of raw material replacement.

2.4 Cost

The costs were calculated using the mix proportions and material costs obtained from a catalog of material costs in Japan (Sekisan-shiryou). In the case of fly ash, the cost may vary so a private company was contacted and the cost of fly ash estimated based on their response. The cost for recycled aggregates was estimated from the price of recycled crushed stone used in road beds, and the cost of water was taken from the Tokyo Metropolitan Bureau Waterworks. The material cost is shown in Table 3 and the cost per mix in Table 4.

Table 3 Material cost

Material	yen/m^3	yen/ton	yen/kg
Water	150	-	0.15
Cement	-	9600	9.6
Fly Ash	-	4000	4
Sand	4050	-	1.55
Normal agg.	3600	-	1.33
Recycled agg.	1500	-	0.62

Table 4 Concrete cost

Series	Cost Yen/m^3
Control	5815
NB-NA	7614
NB-RA	6833
NB-NA-FA50	5950
NB-RA-FA50	5210

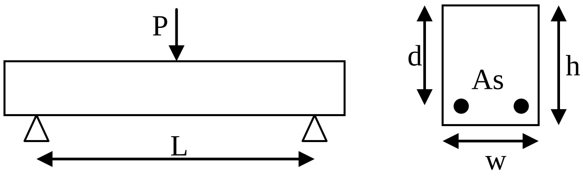
The concrete series with highest cost are NB-NA and NB-RA respectively due to the large amount of cement which is the most expensive material, compared to the other series that have less cement content. The concrete with lowest cost is for NB-RA-FA50 series, in this case mainly because of the amount of recycled aggregate used which is cheaper than normal one.

3. STRUCTURAL DESIGN

3.1 Design methodology & parameters

The structural design was conducted for a simple supported beam with central point load as shown in

Figure 3. For the calculations were assumed the Whitney rectangular stress distribution theory accepted by the American Concrete Institute (ACI), and the reduction factors and other coefficients stipulated by the ACI for designing this type of elements. Just the moment capacity was evaluated since the shear capacity has similar trend; also fracture was not consider.



P: load
L: Length
w: width

h: height = d+5cms
d:effective depth
As: Steel area

Figure 3 Beam assumption

6 Different cases were evaluated where some parameters were set in advance and the others calculated, also one or two parameters were varied in order to observe the trend of unknown parameters when doing it, the different cases are shown in Table 3. For all cases the beam height (h) is equal to depth (d) + 5 cms which is the minimum cover concrete specified by the ACI code.

At this time for calculating the cost were used the beam volume for the concrete cost that was already known and also the amount of reinforcement which cost was obtained from a catalog of material costs in Japan (Sekisan-shiryou). And for the CO$_2$ calculations were just considered the contribution of concrete, since the contribution of steel is very low as compared with that from concrete for a single beam and also for simplicity.

After calculating the unknown parameters, the results were normalized by the control series results with the purpose of being compared with this mix set as reference.

3.2 Case 1

In this the length (L) is varied and the steel area (As) required calculated, then also the CO$_2$ emissions and cost were calculated. The results normalized by control series are plotted in Figure 4.

All the series requires less steel area than control series, except for NB-RA-FA50 series, being the gap bigger while increasing the length (L). The cost is lower or similar than control series for concrete

Table 3 Beam cases

Cases	Parameters						
	Length (L)	Depth (d)	Width (w)	Load (P)	Steel area (As)	CO$_2$ emissions (kg-CO$_2$/m^3)	Cost (Yen/beam)
Case 1	Vary 4-10m	Set 35cm	Set 30cm	Set 10ton	Unknown	Unknown	Unknown
Case 2	Set 5m	Vary 25-55cm	Set 30cm	Set 10ton	Unknown	Unknown	Unknown
Case 3	Vary 4-10m	Unknown	Set 30cm	Set 10ton	Set 14.17cm²	Unknown	Unknown
Case 4	Set 5m	Vary 25-55cm	Set 30cm	Unknown	Set 14.17cm²	Unknown	Unknown
Case 5	Vary 4-10m	Unknown	Set 30cm	Set 10ton	Unknown	Vary 128-320	Unknown
Case 6	Vary 4-10m	Unknown	Set 30cm	Unknown	Set 14.17cm²	Vary 128-320	Unknown

using fly ash, however while increasing the length (L) all series tend to decrease in cost except for NB-RA-FA50 series. From CO_2 emissions it can be seen that the only series with less emissions are those with fly ash.

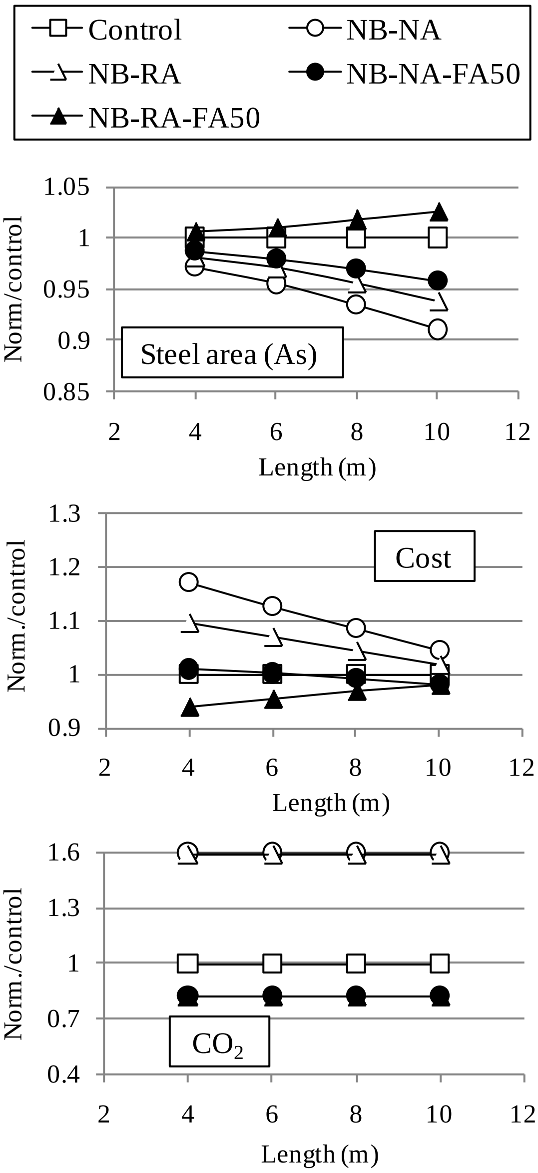


Figure 4 Results for Case 1 with variation in the beam length (L)

3.3 Case 2

In this case the beam depth (d) is varied and the steel area (As), the CO_2 emissions and cost were calculated. The normalized results are in Figure 5. In this case NB-RA-FA50 series requires more steel area than control series, and when increasing the height the all series trend is to converge to the control series curve. The cost is higher for series without fly ash than control one; for NB-NA-FA50 series the trend is to be more expensive than control one, but still so close to it, and for the other series the gap when increasing the depth (d) is marked when compared to control one. The CO_2 emissions of series without fly ash are higher than control one.

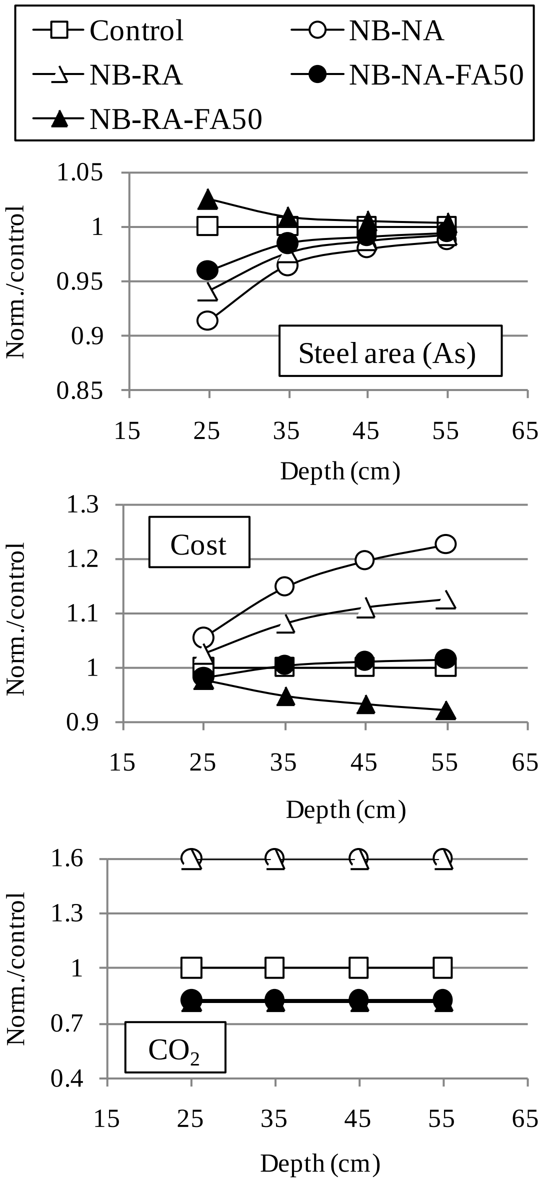


Figure 5 Results for Case 2 with variation in the beam depth (d)

3.4 Case 3

For this, the depth (d) is unknown, then, the CO_2 emissions and cost were calculated. See Figure 6.

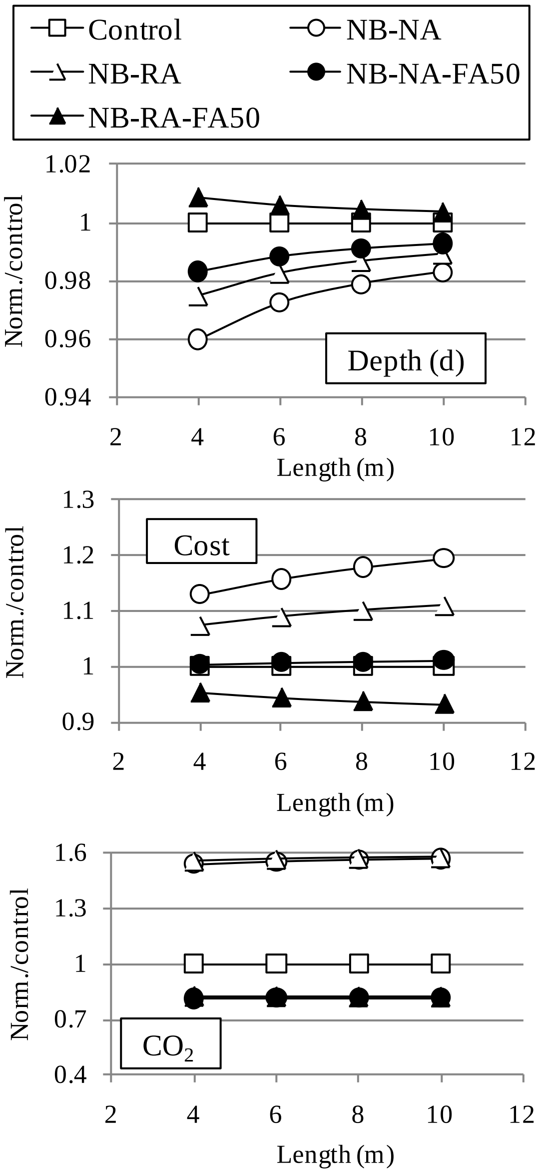


Figure 6 Results for Case 3 with variation in the beam length (L)

All series require less depth (d) than control one excluding NB-RA-FA50, and the trend when increasing the length (L) is to approach to control series. The cost is higher than control series for concrete without fly ash, and for series using fly ash the cost is lower or close control one. The tendency when increasing the length is to increase the difference with control series, except for NB-NA-FA50 series that remains close to it. For the CO_2 emissions the trend in similar to the first cases, however there is a little change in the trend but not so significant.

3.5 Case 4

In this case the parameter varied was the beam depth (d), then the maximun load (P), CO_2 emissions and cost were estimated. Normalized results are shown in Figure 7.

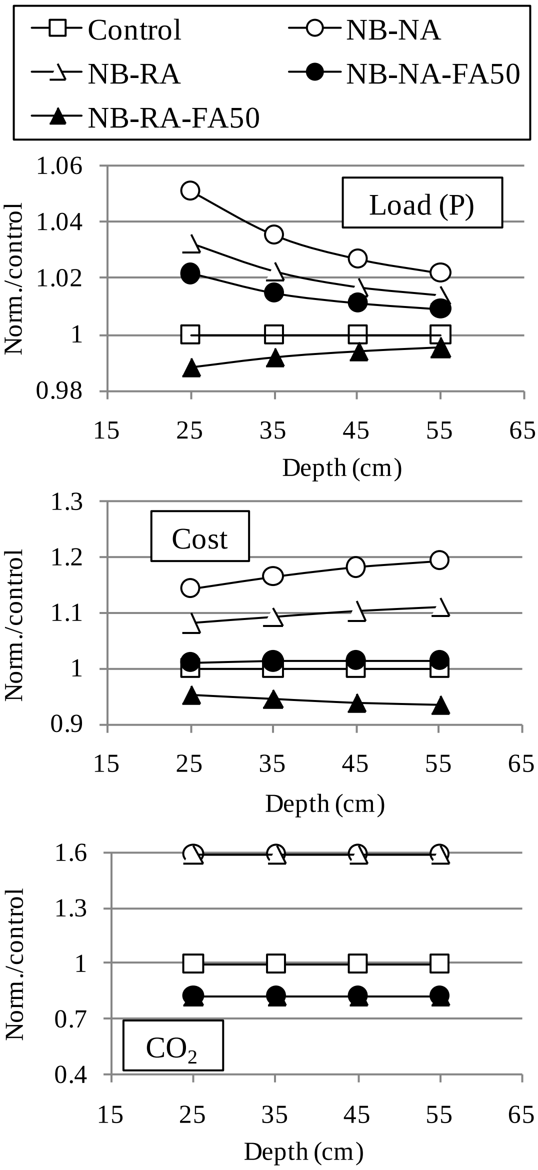


Figure 7 Results for Case 4 with variation in the beam depth (d)

For this cases all the series support more load (P) than the control one excluding NB-RA-FA50 series, and the trend when increasing the beam height (h) is to approach to control series. The cost is higher for series without fly ash and for NB-NA-FA50, but this last is still very close to control series; than change when increasing the beam height (h) is not so significant. Finally the CO_2 emissions shows same behavior as the previous cases where the series without fly ash have far more emissions than control.

3.6 Case 5

For this special case one beam dimension was varied until having the same CO_2 emissions for all series, since every concrete series has different CO_2 emissions per cubic meter; the dimension varied was the depth (d); then the other unknown parameters were calculated (As and cost). And for seeing trend the beam length (L) was varied and all the proccess repeated. Normalized results are shown in Figure 8.

From the results it can be seen that for series without fly ash the decrease in depth (d) is significant compared to control series which leads to an important and constant increase in the required steel area (As) and cost when increasing the span, resulting this in unusual reinforced concrete beams not fulfilling the minimum or maximum requirements, as in the case of NB-RA series where is not possible to calculate the steel area (As) for beam lengths (L) bigger than 6m.

In the other hand for series using fly ash there is a small increment in the beam depth (d), nonetheless the steel area (As) required and cost are lower than control series, with a decreasing tendency when the beam length (L) is increased.

3.7 Case 6

This case has equal procedure as Case 5 varying the beam depth (d) until having the same CO_2 emissions for all series, but the unknown parameter for being calculated were the maximum load (P) and cost. In same way the beam length (L) was varied to see the trend. The normalized results are in Figure 9.

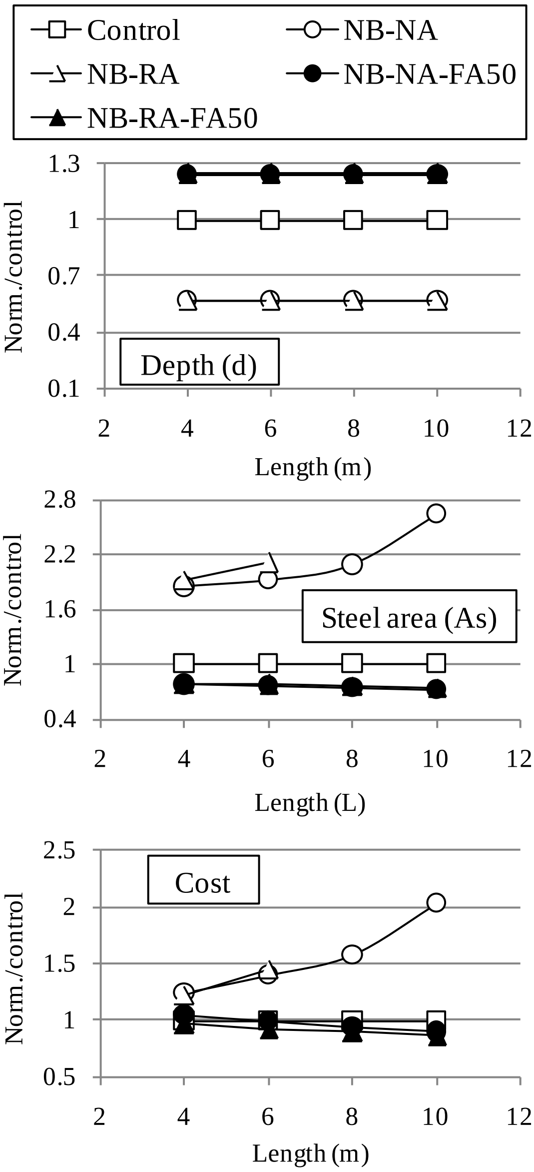


Figure 8 Results for Case 5 with variation in the beam length (L)

In this last case the series with fly ash require more depth (d) supporting more load (L) and are more expensive than control one; conversely the series without fly ash require less depth (d) supporting less load and are less expensive than control one. This case does not show a good balance between the series for the three factors evaluated; the only balance between series is to have the same CO_2 emissions. Besides, there is no change in the tendency.

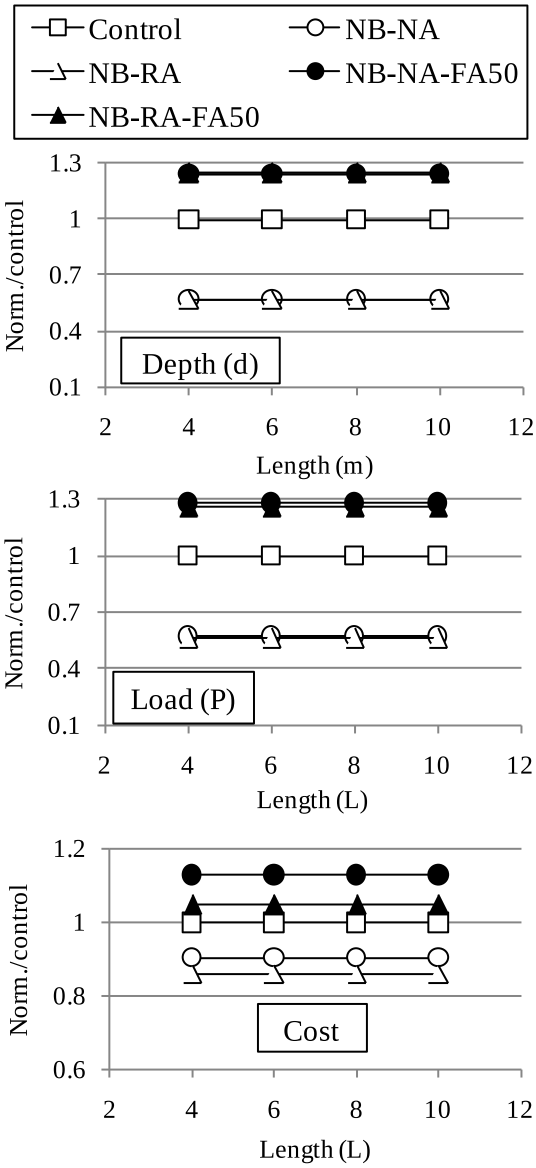


Figure 9 Results for Case 6 with variation in the beam length (L)

4. CONCLUSIONS

From Cases 1 to 4 it can be seen that the best option is NB-NA-FA50 series which results in smaller sections or less steel area (As) or more load (P) and lower cost and CO_2 emissions when compared with control one. However series NB-RA-FA50 that results in bigger sections or requires more steel area (As) or support less load (P) is not far from control series; its cost is very near or lower tan control one, and CO_2 emissions are lower than control series showing a good balance and being a good option as well. Series without fly ash require smaller sections or less steel area (As) or support more load, but their cost and CO_2 emissions are higher than control one, being marked the gap between them and the other series for the CO_2 emissions, specially compared to fly ash series that have less emissions than control series for all the cases. From cases 5 and 6 can be concluded that having the same CO_2 emissions as a starting point could result in non efficient beam designs due to the illogical resultant dimensions or steel area required; however from Case 5 can be said that for series using fly ash this procedure could be a good option. In general the series with best balance are NB-NA-FA50 and NB-RA-FA50 respectively.

After analyzing the results obtained and the factors evaluated we can conclude that utilizing recycled materials for developing concrete is a good alternative, due to its good performance compared to normal concrete when evaluating mechanical performance, environmental impact and cost. Even though the durability factor was not evaluated, the air permeability results could be used as an indirect indicator, showing that all series have better performance when compared with normal concrete as well.

Some specific properties as shrinkage which was not evaluated for this concrete, but knowing based upon previous researches that is a important issue for concrete with low-binder ratio, could reverse the trend of the results obtained in somehow, however when we make a general balance of all the factors than can be brought into play, these reverse in trend could be tackled. Although this and previous research have shown the benefits of using this kind of materials, there is still a big concern and general fear of using them, mainly because the lack knowledge and information, which is the big barrier for making the concrete a more sustainable industry.

ACKNOWLEDGMENT

The authors would like to express their thanks to Mr. Hiromichi Yamashita of the Shibaura Institute of Technology, and all the other members of Kishi-Kato Laboratory who helped in the casting of the concrete series used in this paper.

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