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PERFORMANCE OF COMPOSITE COLUMNS – CONCRETE FILLED STEEL COLUMNS

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ABSTRACT

This paper presents an experimental study on the behavior of short, concrete filled steel tubular columns axially loaded in compression to failure. A total of eight series were prepared, each series comprising of hollow steel tubes, hollow steel tubes filled with concrete and hollow steel tubes cross braced internally with #3 deformed bars welded in transverse direction, alternately at a distance of 150mm centre to centre and filled with concrete. Ultimate strengths achieved experimentally were thereafter compared with the analytical values obtained. Three-dimensional confinement effect of concrete along with support provided by concrete to the thin walls of steel tube to prevent local buckling had a composite effect on the strength of the composite column increasing the compressive strengths by almost 300 to 400%. In addition to the concrete core, the parameters for the testing were shape of the steel tube and its diameter-to-thickness ratio. An equation to estimate the ultimate axial compressive load capacities is proposed for square CFT columns based on this study.

It has been observed that ultimate strength of concrete filled steel tubes under concentric compression behavior is considerably affected by the thickness of the steel tube, as well as by the shape of it's cross section. Although a confining effect in circular CFT columns improves their strength, in square columns only a small increase in axial strength is observed. The axial load-deformation behavior of columns is remarkably affected by the cross-sectional shape, diameter/width-to-thickness ratio of the steel tube, and the strength of the filled concrete. The load deformation relationship for circular columns showed strain-hardening or elastic perfectly plastic behavior after yielding.

RESEARCH SIGNIFICANCE

This study carries significance due to recent advancements in the availability of higher strength steels, better coating materials for protection and high strengths/performance concretes which have expanded the scope of concrete filled steel composite columns with wide ranging applications in various structural systems with ease of construction, highly increased strengths and better performance.

INTRODUCTION

The steel tube in a concrete filled steel tube column acts as longitudinal and lateral reinforcement, and is thus subjected to biaxial stresses, longitudinal compression and hoop tension, whilst the concrete is stressed tri-axially. Due to their excellent structural performance including high strength and ductility, concrete filled steel tubular columns are suitable as structural members for buildings, bridges, trussed structures and deep foundations. The advantages of the concrete filled steel tube columns over other composite systems are that the steel tube provides formwork for concrete, prevents concrete spalling, environmental damage and from offensive agencies whilst concrete in the steel tube supports thin walls and prolongs/prevents local buckling of the steel tubing. The composite column adds significant stiffness to the structure as compared to more traditional steel frame. The advent of higher strength steels, better coating materials for protection and high strengths/performance concretes have expanded the scope of this composite with wide ranging applications in various structural systems with highly increased strengths and better performance.

RESEARCH METHODOLOGY

A total of 36 specimen in four groups comprising two groups of circular shape and two square shapes were tested. 3 specimens in each group were hollow, 3 filled with concrete and 3 braced and filled with concrete. Braced tubes were hollow steel tubes cross braced internally with #3 deformed bars welded in transverse direction, alternately at a distance of 150mm centre to centre and filled with concrete. The height of all specimen was 750mm.
The dimensions of the square columns selected aimed at maintaining similar cross-sectional area as of corresponding circular columns. Hence square columns of Group C have similar cross-sectional area as of circular columns of Group A and similarly Group D has similar cross sectional area as of circular columns of Group B. Other details are given in Table 1. Steel Pipes used for this experimental investigation were made of 250MPa steel. Geometry is shown in Figure 1. Normal OPC was used with crushed limestone coarse aggregates and medium grading sand. 30Mpa concrete, as shown in Table 2, was used in this study. The test strengths of different columns were also compared with strengths given by various codes and also the design equation proposed [Georgios Giakoumelis and Dennis Lam 1]

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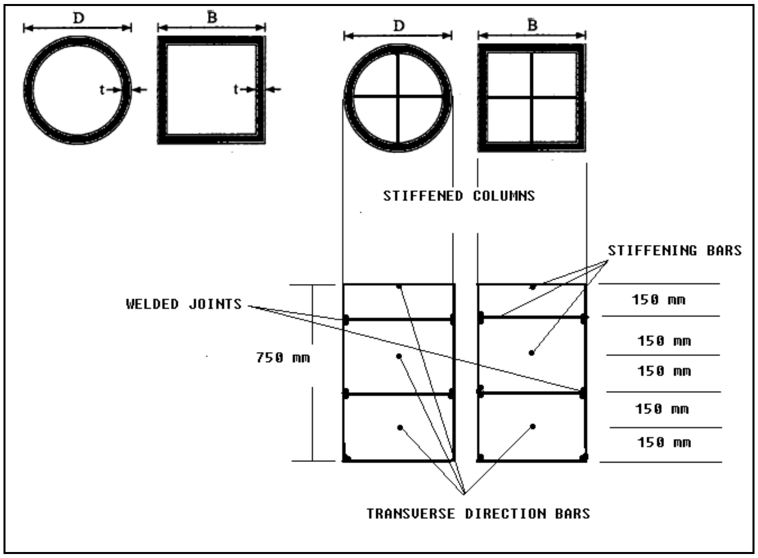

Figure-1. Details of normal and braced columns

CODE CHECK FOR MINIMUM THICKNESS REQUIREMENT – STEEL TUBE

Minimum b/t requirements under LRFD, Eurocode and ACI are given in Table 3. The minimum steel requirement is given in Table 4 confirming that all columns have steel area more than 4%.

TESTING PROCEDURE

The columns were tested in a 200 tons capacity Universal compression testing machine. The specimens were centered in the testing machine in order to avoid eccentricity. The vertical displacement was measured by displacement transducers. The top and bottom faces of specimen were grinded and made smooth and leveled to remove surface imperfections and maintain uniformity of loading on the surface.

Table 1. Geometric properties of steel tubes used.

Ser #	Group	Column Type	Outer Dia mm	Inner Dia mm	Thickness mm	D/t or b/t	L/D or L/b	λ
1	A	Circular	160	155	2.5	64	4.69	19
2	B	Circular	111.25	106.25	2.5	44.5	6.74	27
3	C	Square	125.66	120.66	2.5	50.26	5.97	21
4	D	Square	87.38	82.38	2.5	34.95	8.58	30

Table 2. Properties of concrete used

Specimen	Compressive strength $f_c^{/}$ (MPa)	Average $f_c^{/}$ (MPa)
1	32.61	**31.82**
2	29.74	
3	33.42	

Table 3. Limiting values of b/t

Type	LRFD	Eurocode	ACI code
Square	40	50.6	49.16
Circular	40	85	80

Table-4. Minimum steel check

Ser	Column type	Outer Dia mm	Inner Dia mm	Thickness mm	As sq mm	Ac sq mm	As %
1	A Circular	160	155	2.5	1237	18869	6.15
2	B Circular	111.25	106.25	2.5	854	8866	8.80
3	C Square	125.66	120.66	2.5	1231	14559	7.80
4	D Square	87.38	82.38	2.5	848	6786	11.11

Steel	fy = 250 Mpa
Concrete	fc=30 Mpa

EXPERIMENTAL RESULTS

The stress – strain behaviour of specimen tested is shown in Figures 3 to 5 and load – deformation behaviour is shown in Figures 6 to 8. The test results are listed at Table 5.

HOLLOW STEEL COLUMNS

All columns behaved in almost similar way with yielding strain observed to be between 0.004 and 0.006 and stress in steel around 250MPa at failure. Deformation behavior was also similar. Circular columns failed at about 40% higher loads and deformations on yielding as shown in the stress-strain curves. Square columns started yielding at lower loads as compared to circular ones. Figure-2 shows the yielding of the columns.

FILLED COLUMNS

Almost 400% increased strengths were observed for circular columns with 160mm dia whilst about 100% increase was observed for circular columns with 111.25mm dia. Almost 300% increase in strength was observed for square columns with 125.7 mm side as compared to 100% increase in square columns with 87.4 mm side clearly indicating that higher increase in strength of concrete filled columns was in those with higher concrete area with circular columns performing better than square ones.

Failure strains ranged up to 12mm whilst failure mode in all cases was observed to be due to crushing of concrete resulting into buldging of steel column, failing thereby in yielding as shown in Figure 2.

Figure-2. Photographs showing failure modes And test setup of columns

FILLED AND BRACED COLUMNS

Braced and concrete filled steel columns were observed to behave almost similar to the concrete filled columns without bracing. Bracing did not improve the strength because of improper filling of steel tubes due to presence of bracing at every 150mm distance along with the length of the column which falls into short columns category where slenderness effects did not come into play. The failure was due to crushing of concrete and thereby yielding of steel due to buldging out.

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Table 5. Results of experimental testing

Ser	Column type	Outer Dia mm	Inner Dia mm	As sq mm	Ac sq mm	Actual capacity KN
1	A circular hollow	160	155	1237	0	290
2	-do- filled	160	155	1237	18869	1153
3	-do- filled & braced	160	155	1237	18869	1090
4	B circular hollow	111.25	106.25	854	0	237
5	-do- filled	111.25	106.25	854	8866	526
6	-do- filled & braced	111.25	106.25	854	8866	422
7	C Square hollow	125.66	120.66	1231	0	179
8	-do- filled	125.66	120.66	1231	14559	594
9	-do- filled & braced	125.66	120.66	1231	14559	595
10	D Square hollow	87.38	82.38	848	0	215
11	-do- filled	87.38	82.38	848	6786	450
12	-do- filled & braced	87.38	82.38	848	6786	407

STRENGTH COMPARISON BY DESIGN CODES

The values calculated by this method are listed at Table 6 and 7. It is observed that the capacities given by ACI code are too conservative whereas those calculated by using proposed equation are more realistic, especially for circular columns.

EUROCODE-4

The ultimate axial force of a square column is: $N_{pl.R} = A_a f_y + A_c f_c$

For circular columns confinement effects have to be incorporated if relative slenderness $\bar{\lambda}$ is less than 0.5 then $\bar{\lambda} = \sqrt{N_{pl,R} / N_{cr}}$

where $N_{cr} = \Pi^2 (EI)_e / l^2$, $(EI)_e = E_a I_a + 0.8 E_{cd} I_c$ and $E_{cd} = E_{cm} / \gamma_c$

E_{cm} = Secant Modulus of concrete 3.2.4.1 (EC4) Table 3.2

γ_c =1.35 is a safety factor A.3.1 and A.3.4 of EC2

Values of $\bar{\lambda}$ for 160mm and 111.25 mm circular columns were 0.22 and 0.44 thereby showing that confinement effects have to be included in design calculation. With the equation as

$$N_{pl.R} = A_a n_2 f_y + A_c f_c' [1 + n_1 (t/d)(f_y / f_c')]$$

Where n_1=4.9 – 18.5 $\bar{\lambda}$ + 17 $\bar{\lambda}$^2 and n_2=0.25(3+2$\bar{\lambda}$)

The values calculated for square and circular columns by this method are listed in Table 6. Although the values are a bit conservative but even then, are to some extent accurate for both circular and square columns. The incorporation of confinement effect adds up to the estimation of ultimate capacity of circular columns.

ACI AND AUSTRALIAN CODE

The ACI and Australian Standards use the same formula for calculating the ultimate load. Neither code takes into consideration the concrete confinement. The limiting thickness of steel tube to prevent local buckling is almost same for both codes and is calculated in succeeding paragraphs and tabulated too. The ultimate load for short square, rectangular and circular columns is determined by:

$$N_u = 0.85 A_c f_c' + A_s f_s$$

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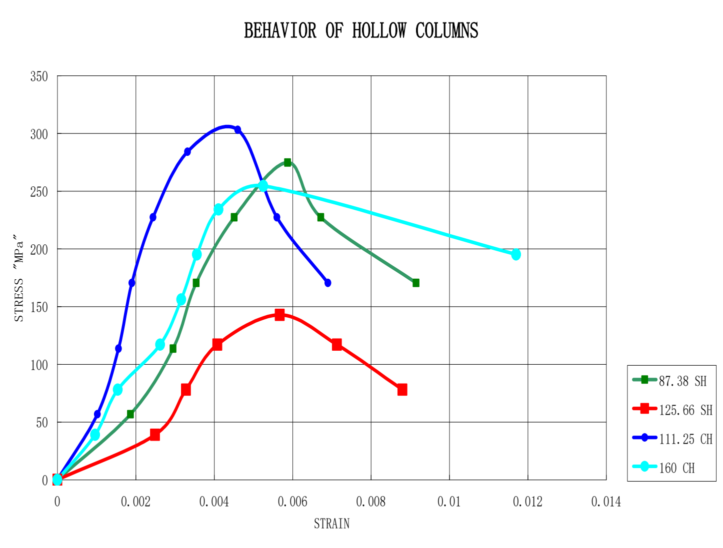

Figure 3. Stress – strain curve of braced columns

MODIFIED EQUATION

Since the above values are too conservative, a modification for ACI and AS equation proposed by Georgios Giakoumelis and Dennis Lam [1]. A coefficient is proposed for the ACI/AS equation to take into account the effect of concrete confinement on the axial load capacity of concrete filled circular steel tube, suggesting the revised equation as follows:-

$$N_u = 1.3 A_c f_c^{/} + A_s f_s$$

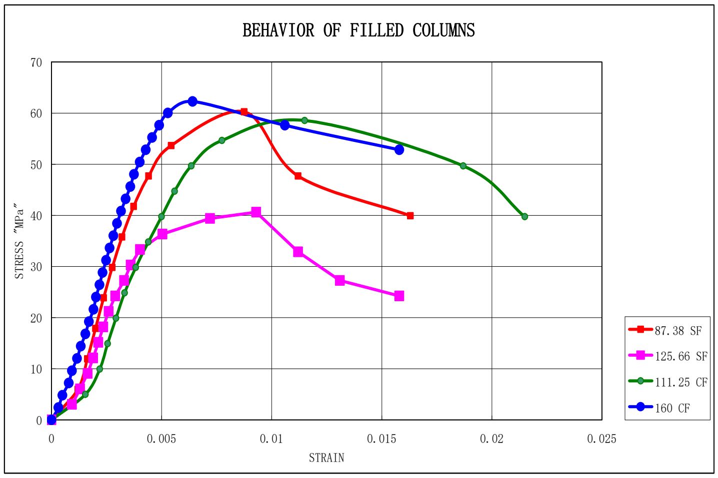

Figure 4. Stress – strain curve of filled columns

LRFD CODE

The ultimate load is given by: $P_n = A_s F_y + 0.85 A_c f_c^{/}$

$$\frac{P_n}{A_s} = F_{my} = F_y + 0.85 \frac{A_c}{A_s} f_c^{/}$$

For composite columns $F_{my} = F_y + c_2 f_c^{/} (\frac{A_c}{A_s})$ where c_2 = 0.85 for pipes and hollow square sections.

$E_m = E + c_3 E_c (\frac{A_c}{A_s})$, $c_3 = 0.4$ for pipes and hollow square sections.

$\lambda_c = \frac{KL}{\Pi r_m}\sqrt{\frac{F_{my}}{E_m}}$ and $F_{cr} = (0.658)^{\lambda_c^2} F_{my}$

Nominal strength P_n can be calculated as $P_n = A_s F_{cr}$

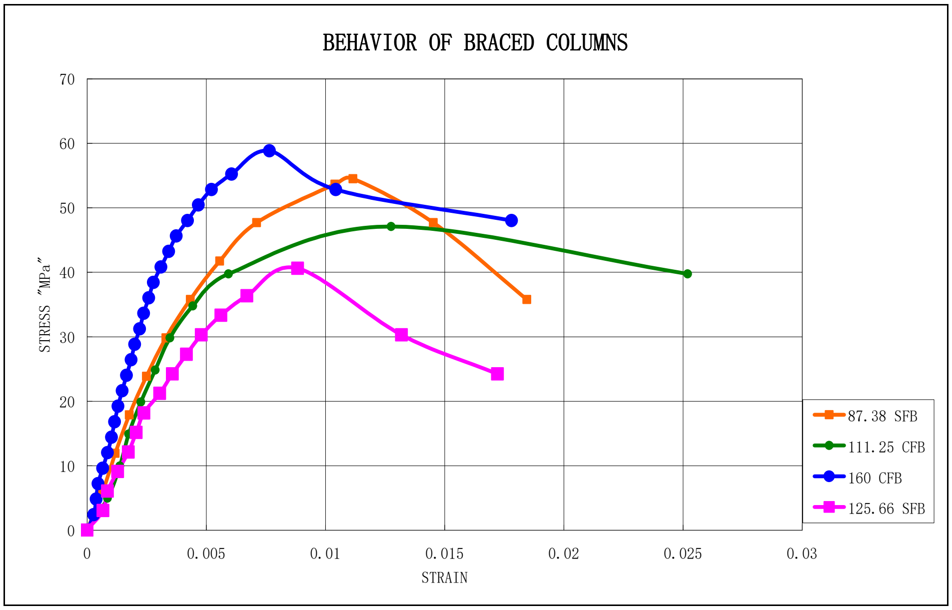

Figure 5. Stress – strain curve of braced columns

EFFECT OF CONCRETE CONFINEMENT

For concrete filled circular sections, the confinement effect of concrete increases the concrete strength. The effect of confinement is considered when the relative slenderness, $\bar{\lambda}$ is less than 0.5. Due to concrete confinement the stress bearing capacity of concrete increased to almost double in circular columns. It implies that when diameter is kept constant and steel thickness is increased, the confinement factor increases thereby increasing the compressive strength of concrete [9].

FAILURE MODES

Almost all columns failed due to local buckling and concrete crushing. Local buckling took place in inelastic range and after this concrete crushing followed. The failure mode of almost all columns at bottom or top was a typical crushing failure mode where the steel wall was pushed out by the concrete core, which in turn was confined by the steel. When the steel was removed from the specimen after failure, the concrete was found to have taken the shape of the deformed steel tube, which illustrates the composite action of the section.

CIRCULAR COLUMNS

In the initial stages of loading of the circular CFT columns subjected to axial load, Poisson's ratio for the concrete is lower than that for steel; therefore, a separation between steel tube wall and concrete core takes place. As the load increases, the longitudinal strain reaches a certain critical strain, the lateral deformation strength and the nominal ultimate load is provided by the confining effect on concrete strength, and this gain depends upon the tube strength. Figures 3 through 7 indicate the behavior of circular columns as much better as compared to square ones for both hollow and filled series. At failure, ring shaped buckles developed outwards mostly near ends i.e top or bottom. Equation developed by Georgios Giakoumelis and Dennis Lam [1] predicts the ultimate strength almost accurate for circular columns.

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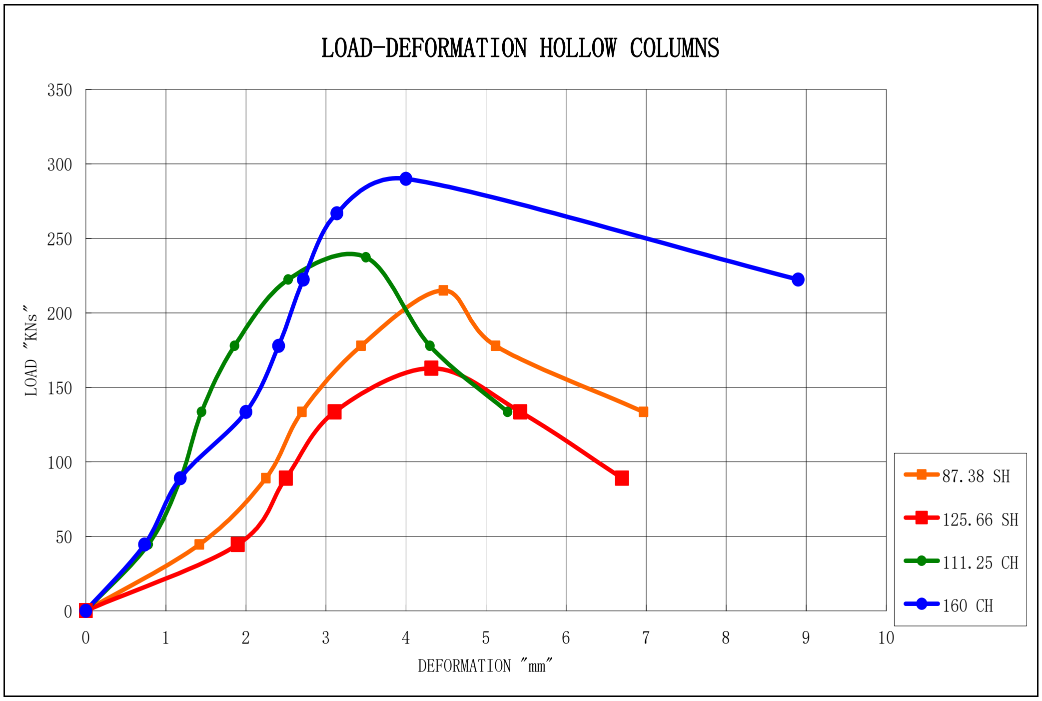

Figure 6. Load deformation curve of hollow columns

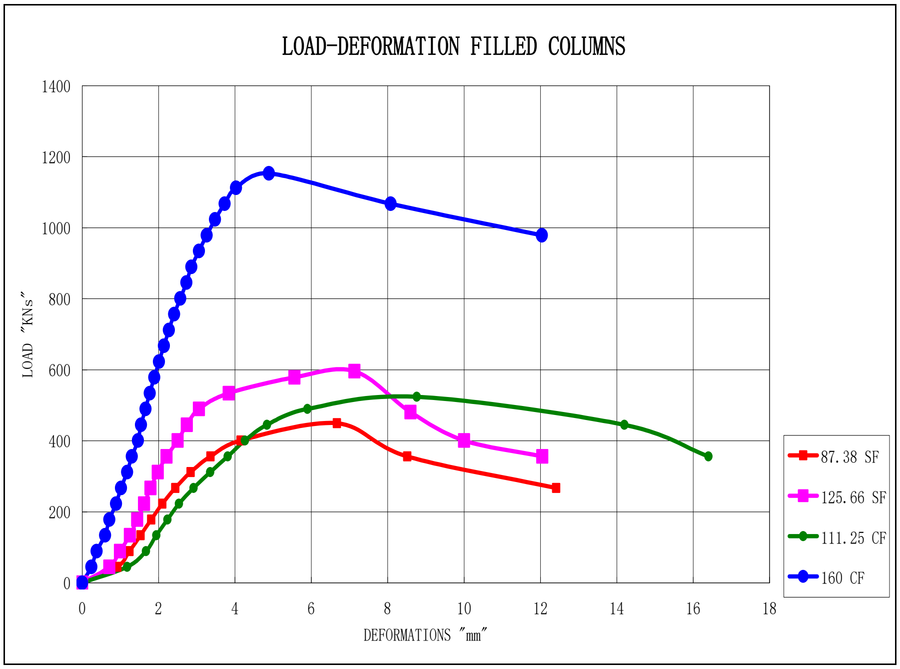

Figure 7. Load deformation curve of filled columns

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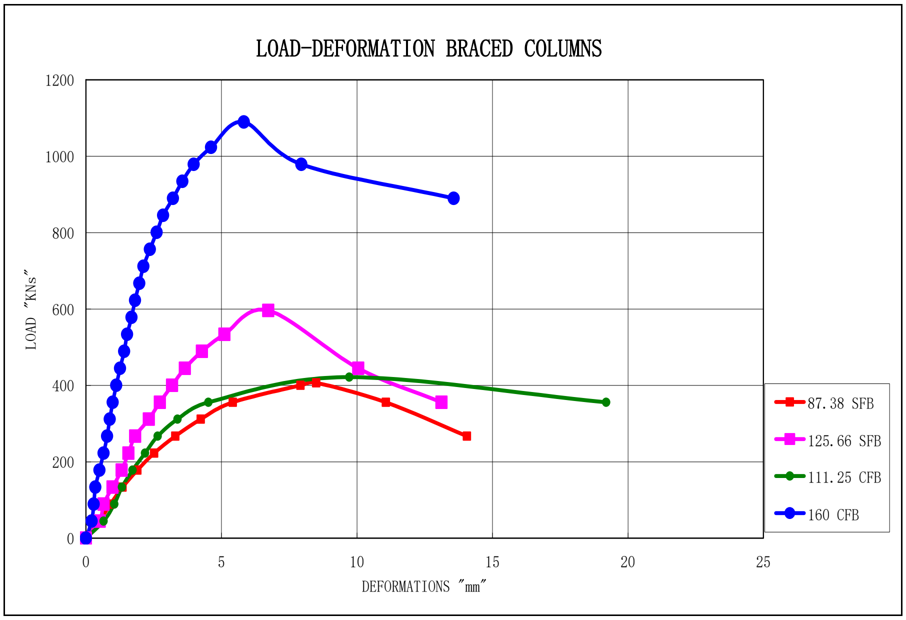

Figure 8. Load deformation curve of braced columns

Table 6. Comparison of Results

Ser	Column type	Actual capacity kN	Pu LRFD kN	Pu ACI kN	Pu Eurocode kN	Georgios Equation kN
1	A circular hollow	290	341	341	309.25	309.25
2	-do- filled	1153	698	784	909	986.27
3	-do- filled & braced	1090	698	784	909	986.27
4	B circular hollow	237	235	235	213.50	213.50
5	-do- filled	526	380	443	454	531.61
6	-do- filled & braced	422	380	443	454	531.61
7	C Square hollow	179	339	339	307.75	307.75
8	-do- filled	594	551	681	788	830.13
9	-do- filled & braced	595	551	681	788	830.13
10	D Square hollow	215	234	234	212	212
11	-do- filled	450	293	393	428	455.48
12	-do- filled & braced	407	293	393	428	455.48

SQUARE COLUMNS

In the case of square columns, it is necessary to take into consideration a capacity reduction due to local buckling of the steel tube wall of the column with large *B/t* ratio rather than the confinement effect of the steel tube. Also, the compressive strength decreases as the size of square columns increases as shown in Figures 3 to 8. An equation for square columns is suggested to be used for calculating the ultimate strength as:

$N_u = 1.10 A_c f_c^{\prime} + A_s f_s$ which gives fairly safe results.

CONCLUSION

The experiments have shown that strength increase in circular concrete filled steel columns is more than that of square ones. Increase in strength of circular columns was observed to be 400% higher as compared to about 300% higher strengths for concrete filled square columns. Local buckling of steel tube was observed in both hollow and filled square columns. Almost all concrete filled steel columns behaved in a fairly ductile manner. Concrete filled steel columns with relatively higher concrete area proportionately increased the ultimate strength.

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Table 7. Comparison of ultimate loads given by different codes

Ser	**Type**	**Actual capacity kN**	**Pu LRFD KN**	**%**	**Pu ACI kN**	**%**	**Pu Eurocode kN**	**%**	**Georgios Equation kN -**	**%**
1	Circular	1153	698	- 40	784	- 32	909	- 21	986	- 14
2	Circular	1090	698	- 35	784	- 28	909	- 17	986	- 9.5
3	Circular	526	380	- 28	443	- 16	454	- 14	531	+ 1
4	Circular	422	380	- 10	443	+ 5	454	+ 7	531	+ 25
5	Square	594	551	- 7	681	+ 13	709	+ 16	830	+ 28
6	Square	595	551	- 7	681	+ 13	709	+ 16	830	+ 28
7	Square	450	293	- 35	393	- 13	399	- 11	455	+ 1
8	Square	407	293	- 28	393	- 3.5	399	- 2	455	+ 11

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PROPERTIES OF HIGH STRENGTH CONCRETE CONTAINING CRUSHED LIMESTONE WASTE

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ABSTRACT

This experimental study aimed at evaluating the properties of high strength concrete containing crushed limestone waste widely produced from limestone processing industry as supplementary cementing material. A small percentage of limestone powder is traditionally used in cement and masonry to improve workability and in concrete as fine filler however limited research has been carried out on high strength concretes with partial replacement of limestone crush as supplementary cementing material. This study investigated the properties of high strength concrete made from Portland slag cement comprising 50% cement and 50% ground granulated blast furnace slag, natural aggregates and sand where crushed limestone waste was added to cement by replacing slag cement in the percentages of 10% and 20%. Wide ranging investigations covering most aspects of mechanical behavior and permeability were carried out for various mixes for compressive strengths of 60MPa and 80MPa. Compressive strengths of concrete specimen with partial replacement of 10% and 20% limestone waste were observed to be higher by about 4 to 12% than the control specimen. Flexural strengths were also observed to be higher by 12 – 13%. Higher elastic moduli and reduced permeability were observed along with better sulphates and acid resistance. Better strengths and improved durability of such high strength concretes containing up to 20% limestone waste make it a more acceptable material for major construction projects in addition to consuming this massively produced waste material for useful purposes along with reducing its disposal problems.

Keywords: Crushed limestone waste, sustainable construction, supplementary cementing material, high strength concrete, cement replacement material.

INTRODUCTION

Use of environment friendly materials has gained huge popularity world-wide thereby resulting into greener practices. Sustainable and emerging green practices leading to environmentally friendly materials have led to use of many waste materials in manufacturing of cement and concrete Most waste materials produced from various human, agricultural and industrial activities are being investigated for useful purposes in addition to improving the environment worldwide. Agricultural wastes like rice straw and husk, industrial waste like slag, fly ash, stone/ limestone dust and brick/ concrete waste from demolition of old structures have been used in manufacturing concrete [1-12]. Ongoing research has led to newer chemicals and materials which have improved the quality of construction immensely. Concretes with improved strengths and durability characteristics are now readily available.

Huge amounts of limestone are quarried and used worldwide in construction and landscaping purposes. Large amount of waste is generated during cutting and sawing process of limestone which includes fragments, fine powder and slurry. 60% to 70% of the stone is believed to be wasted in this process, of which around 30% is believed to be fine powder [2]. Large amount of limestone waste generated from the processing has no useful utilization and is disposed off as waste, occasionally used for landfill purposes. Use of limestone waste as a binder and a supplementary cementing material for partial replacement of cement in concrete will certainly reduce the concrete costs and will hence result into cheaper construction. Improved strength and durability characteristics of concrete will certainly make it a popular material. Bulk use of this waste material can consume large quantities of this waste in construction industry, thereby reducing the burden on the environment. In the absence of any worthwhile research in this field, this study was undertaken to assess the properties of concretes produced by using crushed limestone waste as partial replacement of slag cement in concrete.

Presently, a maximum of up to 70% of slag is added to Portland cement though 50% slag is the usual amount added to Portland cement. Due to the primary issue associated with the use of slag cement in pavement construction being the reported loss of durability (salt scaling resistance) Federal Highways Agency vide its instruction FHWA-RD-97-148 - User Guidelines for Waste and By-product Materials in Pavement Construction restricts maximum of 25% blast furnace slag to be used with Portland cement. 2 to 3% lime is usually added to cement in the production stage to react with ettringite to form stable products during hydration. Large amounts of CO_2 are emitted during the production of cement estimated to be around 1 ton CO_2 per ton of clinker, if no precautions are taken to reduce these emissions. It is estimated that CO_2 emissions from cement manufacturing industry only account for about 7% of the total CO_2 industrial emissions in the world [1]. Use of supplementary cementitious materials (SCMs) like blast-furnace slag, fly ash and other waste materials like crushed limestone waste and rice husk ash etc. can reduce the quantities of Portland cement thereby reducing CO_2 emissions largely. The use of such SCMs also improve the performance concretes like better workability, low permeability, improved durability with better resistance to sulphates and chlorides as well as higher compressive and flexural strengths. Concrete industry is one of the largest users of materials worldwide. Use of such industrial and agricultural waste products in large quantities does reduce the cost of concrete and hence the overall costs of construction too.

The main composition of waste limestone powder is CaCO3 which does possess cementing properties hence can be used as cementitious material or a supplementary cementing material. European code EN 197-1:2000, allows up to 35% of limestone addition in Portland-limestone cement, or total of 35% of limestone plus other SCMs in composite cement [1]. While some of limestone is used up in stabilizing the ettringite formed during hydration of cement, some of it may act as filler or plasticizer in concrete to improve its mechanical properties [1]. Typically, slag cements have low early strengths and high long-term strengths. Addition of limestone powder in cement tends to improve its low early strength with some improvement in long term strength and durability [2].

RESEARCH SIGNIFICANCE

This research investigates the possible use of crushed limestone waste as a supplementary cementing material to replace slag cement in concrete and study its characteristics. Improved strength and durability characteristics of such concrete can reduce the disposal problems of this waste produced worldwide in massive quantities along with providing a better product i.e. high strength concrete with improved strength and durability characteristics. Environment is hugely benefitted as a consequence of utilizing this waste for constructive purposes

MIX DESIGN

High strength concrete mixes were designed for concrete strengths of 60 & 80MPa based on the Design of Normal Concrete Mixes method of Department of Environment - Transport and Road Research Laboratory, London, UK [1[3]. The design graph for compressive strength versus w/c ratio is restricted up to maximum w/c ratio of 0.3 hence linear projection of compressive strength versus w/c ratio was considered beyond the limiting w/c ratio of 0.3. Characteristic strengths of 60 and 80MPa were selected for trial concrete mixes for concrete testing. These high strength concrete mixes were designed using ordinary Portland slag cement, crushed stone coarse aggregates (maximum 15mm diameter) and medium grade sand. Control mix contained 100% Portland slag cement while other two mixes comprised of 10% and 20% slag cement replaced with crushed limestone powder waste. Slag cement was thoroughly mixed with 10% and 20% replaced limestone powder in drum mixer for 2 minutes before using it for concrete. Crushed limestone waste used was 100% passing #50 sieves. Quantities of materials used in the concrete mixes are given in Table 1. Approximately 1-1/2% of superplasticizer with a maximum of 10 l/m^3 was used to maintain workability and slump in the range of 90 to 120mm for better compaction and specimen formation.

Table 1. Design of concrete mixes

Characteristic Strength MPa	W/C Ratio	Cement kg	Sand Kg	Water Kg	Aggregate kg	Super Plasticizer
60	0.35	460	510	161	1335	7 l/m^3
80	0.29	570	480	165	1260	10 l/m^3

TESTING OF CONCRETE

Six specimens each from three different batches were used in all tests. All specimens were cured in water at 20^0 C for 42 days before testing. Table 2 gives the details of tests and specimen used for various tests.

DISCUSSION OF TEST RESULTS

The properties of the high strength concrete specimen are summarized in Tables 3 and 4.

Compressive Strength

Compressive strength tests on cubes at 7, 28 and 42 days showed that the rate of development of strength of concrete specimen containing 10% and 20% slag cement replaced with crushed limestone waste was similar to normal slag cement concrete samples. The compressive strengths of high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste were higher by 2 to 3% than the control specimen. Specimen cured up to 42 days were tested as strength development of concrete with low w/c ratios spans over longer durations and specimen require excess of external water for hydration [14]. High strength concrete with 10% and 20% % slag cement replaced with crushed limestone waste both developed 80 to 82% of its 28day characteristic strength in 7 days like control mixes. Cylinder strengths of concrete with 10% and 20% % slag cement replaced with crushed limestone waste varied from 87 to 89% of cube strength similar to control mixes. Complete section of the test specimen failed explosively on reaching failure loads which is characteristic of high strength concretes [14]. Keeping in view the test safety and to prevent any damage due to such sudden failure of test specimen, a loading rate of 0.15 to 0.2 N/mm^2/s was maintained which is slightly lower than 0.2 to 0.4 N/mm^2 specified by BS1881: Part 116:1983. Compressive strengths of test specimen are given in Table 3.

Table 2. Details of Testing

Type of Test	Test Sample
Compressive strength/density	150mm cubes, 150mm diameter, 300mm long cylinders
Flexural strength	150x150x750mm beams
Stress/strain behavior	150mm diameter, 300mm long cylinders.
Static modulus of elasticity	150mm diameter, 300mm long cylinders.
Dynamic modulus of elasticity	150x150x750mm beams.
Ultrasonic pulse velocity	150mm cubes.
Initial surface absorption	150mm cubes.
Density	150mm cubes
Sulphate and Chloride resistance	150mm cubes. (Immersed in 5% H2SO4 and 5% HCl solutions for 90 days and measuring weight loss)

Note:- All specimen were cured in water at 20^0 C for 42 days before testing.

Table 3. Properties of concrete

W/C Ratio	Mixes	Cube Strength 7 Days MPa	Cube Strength 28 Days MPa	Cube Strength 42 Days MPa	Cylinder Strength MPa	Flexural Strength MPa
0.35	Control	49	61	64	54	7
	A	50	63	66	56	8.1
	B	52	64	67.6	58	9
0.29	Control	64	79	82	69	8
	A	66.4	83	84	72	9.3
	B	70	86	88	76	10

Note:-
Control – 100% Slag Cement
A – 10% Slag cement replaced with crushed limestone
B – 20% Slag cement replaced with crushed limestone

Flexural Strength

The flexural strength of high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste both were observed to be higher by 15 to 20% as compared to control specimen. Slightly higher compressive strengths with improved hydration and better packing due to addition of limestone results into higher flexural strengths of concrete with slag cement replaced with crushed limestone waste.

Stress/strain Behavior

The slopes of the stress/strain curve for high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste were seen to be similar to the curve for control specimen, typical for high strength concrete. Stress/strain curves were found to be linear up to the point of failure. Slightly higher static and dynamic moduli of elasticity were observed for high strength concretes with 10% and 20% slag cement replaced with crushed limestone waste. Idealized stress/strain curves for all specimen are given in Figure 1.

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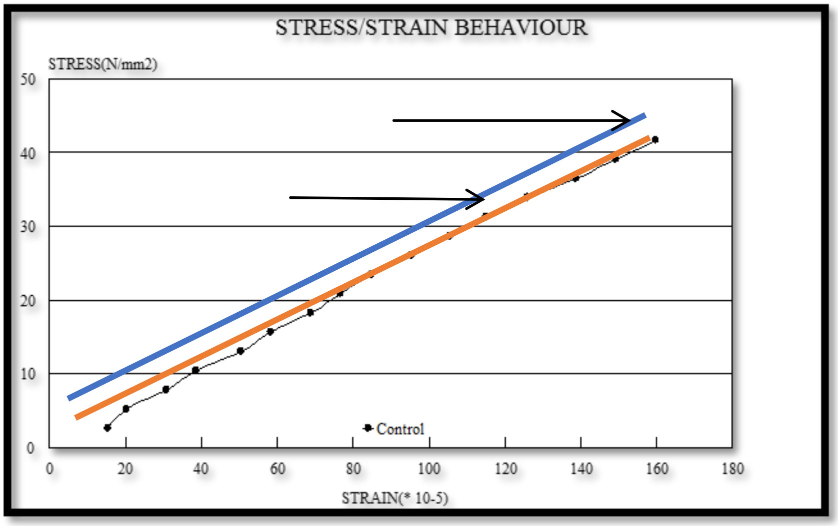
Table 4. Properties of concrete

W/C Ratio	Mixes	ISAT ml/m^2/s	Elastic Modulus MPa	Dynamic Modulus MPa	Pulse Velocity km/s
0.35	Control	0.2	36340	51378	4.7
	A	0.18	37420	54145	5.0
	B	0.16	38951	56610	5.2
0.29	Control	0.19	37620	54563	4.8
	A	0.16	38897	57490	5.1
	B	0.15	39760	59194	5.3



Note: -
Control – 100% Slag Cement
— – 10% Slag cement replaced with crushed limestone
— – 20% Slag cement replaced with crushed limestone

Figure 1. Idealized Stress – Strain Curves

Static Modulus of Elasticity

Static Modulus of Elasticity for high strength concrete containing 10% and 20% slag cement replaced with crushed limestone waste were observed to be about 2 and 3% higher than the control specimen, respectively. Average values for Static Modulus of Elasticity varied from 38000 to 39760 MPa for high strength concrete with 20% slag cement replaced with crushed limestone waste as compared to 36340 to 37670 MPa for control mixes. Test results for Static Modulus of Elasticity are given in Table 4.

Dynamic Modulus of Elasticity

Dynamic Modulus of Elasticity for concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5% and 10% higher than the control respectively. Results of testing for Dynamic Moduli of Elasticity of various specimen are given in Table 4.

Ultrasonic Pulse Velocity

Specimen containing 10% and 20% slag cement replaced with crushed limestone waste were observed to have pulse velocities of 5 and 5.2 km/s respectively as compared to average velocity of 4.8 km/s for control mixes. Hence ultrasonic pulse velocity in the case of concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5 to 10% higher than the control mixes. Higher pulse velocities are certainly due to better hydration, higher density and reduced voids in the high strength concretes containing partial replacement of slag cement with crushed limestone waste. Table 4 gives the test results for ultrasonic pulse velocities for different specimen

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Density of Hardened Concrete

The average saturated and oven-dried densities for high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste were 2462 and 2452kg/m^3 respectively compared to control mixes which were 2440 and 2427kg/m^3, respectively. Hence the saturated and dry densities of concrete with 10% and 20% slag cement replaced with crushed limestone waste are about 1 to 1-1/2% higher respectively than the control mixes. Higher densities with 10% and 20% slag cement replaced with crushed limestone waste are due to better hydration, reduced voids and better packing of materials as compared to control mixes. Due to higher content of fines and cementitious material with low w/c ratios, the unhydrated cementitious material acts as filler too to densify the concrete, as the hydration process continues over longer duration.

Initial Surface Absorption (ISAT)

Initial surface absorption for concrete with 20% slag cement replaced with crushed limestone waste was observed to be lowest with around 20% lower whilst for concrete with 10% slag cement replaced with crushed limestone waste it was around 10% low as compared to the control. The values are compared with the guidelines given by the Concrete Society Technical Report # 31 [15]. Table 4 gives the values of initial surface absorption tests for various test specimen.

Sulphate and chloride resistance

Average weight loss of specimen due to submersion of specimen in HCL solution resulted in average weight loss of 4% for control specimen as compared to 2.6% and 2.1% for concrete with 10% and 20% slag cement replaced with crushed limestone waste respectively. Similarly, for Sulphate resistance testing of specimen by submersion of specimen in H_2SO_4 solution resulted in average weight loss of 3% for control mixes while 1.7% and 1.2% for specimen containing 10% and 20% slag cement replaced with crushed limestone waste respectively. Concrete with partial replacement of 10% and 20% slag cement replaced with crushed limestone waste is found to be twice better in acidic environment as well as in sulphates environment as compared to control mixes. Better chloride and sulphate resistance for concrete with 10% and 20% slag cement replaced with crushed limestone waste is mainly due to the better hydration, reduced permeability and higher densities of concrete with partial replacement of slag cement with crushed limestone.

Shrinkage

Shrinkage of 10% and 20% slag cement replaced with crushed limestone waste specimen was observed to be similar to control specimen. Shrinkage of specimen was observed over a 90-day period

CONCLUSIONS

The performance of concrete with partial replacement of slag cement replaced with crushed limestone waste has proved to improve performance. Compressive strengths of 60 & 80MPa can be attained with up to 20% slag cement replaced with crushed limestone waste in normal concrete mixes with slag cement. Better packing, reduced voids, improved workability and better hydration due to fines dispersal in the mix resulted into better performance. 2% to 3% higher compressive strengths could be achieved with 10% and 20% slag cement replaced with crushed limestone waste as compared to control mix. Flexural strength of high strength concrete with 10% and 20% slag cement replaced with crushed limestone waste are observed to be higher by 15 to 20% as compared to control specimen. The average Static Modulus of Elasticity for concrete specimen containing 10% and 20% slag cement replaced with crushed limestone waste was 2 to 3% higher than control mixes comprising slag cement. The average Dynamic Modulus of Elasticity for concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5% and 10% higher respectively as compared to control specimen. Ultrasonic Pulse Velocity in the case of concrete with 10% and 20% slag cement replaced with crushed limestone waste was observed to be 5 to 10% higher than the control mixes. Saturated and dry densities of concrete with 10% and 20% slag cement replaced with crushed limestone waste are about 1% to 1-1/2% higher respectively than the control mixes. The performance of concrete with partial replacement of 10% and 20% slag cement replaced with crushed limestone waste was almost twice better in acidic environment and in sulphate environment as compared to control mixes. Shrinkage of specimen for all mixes was observed to be similar over a 90 days period.

AUTHOR'S CONTRIBUTIONS

Tahir Kibriya 100%
Group1 - Conception and design, Acquisition of data, Analysis and interpretation of data
Group 2 - Drafting the article, Critical revision of the article
Group 3 - Final approval of the version to be published

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FACTORS CURBING THE ECONOMIC CONVERGENCE OF UKRAINE IN THE EUROPEAN REGION

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ABSTRACT
The problems of economic convergence of Ukraine to the European Economic Area were considered. The authors' opinion was expressed that the negative impact on the state of the national economy comes not so much economic or political factors, but more – latent factors that are destructive and deepen economic and social shocks in Ukrainian society. Author’s attention was focused on two issues: politicized oligarchy and passive behavior of participants in economic relations. Measures for solving these and other problems that constrain Ukraine's real economic convergence in the European Region were identified in the article.

Keywords: convergence, public debt, the shadow economy, government regulation, structural changes, competitiveness.

Introduction. Formed in Ukraine's economy the market type is the result of faulty models, transformation of ownership by privatization, business relations and Government. Despite the fact that the most promising and strategic businesses and industries have moved into private hands and demonopolised almost all commodity markets, it did not become a factor of economic success – conditions for economic competition are not created, and the market mechanisms or not operating or non-inhibited monopoly entities oligarchic grouping. This, in turn, not contributes to a stable and progressive movement of national economy of Ukraine in the direction of qualitative structural changes. The extremely slow development of the real economy, social infrastructure of the national economy of Ukraine, which hinders the process of economic convergence with the European Union, i.e. the reduction of the gap in terms of economic development, and thus – the acceptance of the EU as an equal partner and as an active subject, not as an object of economic relations. The classic is the idea that the formation of an efficient structure of the national economic system and its convergence with developed countries depends on the alignment of interests on an international level with other countries, different according to the degree of development and integration into the global economic system. That is, it is refers to the multi-vektor integration, which involves not only the emergence of new forms of organization of the market, customs and monetary space, but convergence and mutual adaptation of national economies [1]. However, the economic situation in Ukraine today, indicates that such integration is not enough. Government tries to reassure their citizens about the fact that doing everything possible for the accession to the European Union, but the actual shift is almost absent. In this context it is urgent study of factors which hinder the economic convergence of Ukraine in the European region.

The latest sources of research and publications review. Problems of convergence of EU economies are seen in the works of Z. Darvasa [2], E. Zervoyani [3], B. Makkoviaka [4], M. Stockera [5], J. Fagoyette [6] and others. Their thoughts about the Maastricht Treaty and problems of his points on economic convergence expressed by M. Baun [7], E. Best [8], F. Vanhonaker [9], F. Larsen [10].

The issue of convergence and mutual adaptation of national economic systems was given considerable attention by such scientists as V. Bakingem [11], O.V. Bulatova [12], E.Y. Vinokurov [13], K. G. Grigorian [14], N. Landret, D.S. Kolander [15], M.M. Kornev [16], M. Ma rini [17], A.A. Sishchuk [18], who are considering the problem of convergence with various aspects. J. Galbraith considers the technological version of convergence, i.e. in his theory of the problem of convergence of the two systems, he approached in terms of sizes of production, it’s technical and organisational side. The inevitability of technological convergence scholar justifies the fact that developed countries are inherent in large scale production, regardless of their political system, which need «about similar systems of planning and organization» [19]. V. Bakingem sees the convergence of single overall economic system [11].

With the formation of the neoclassical theory of R. M. Salou and its subsequent modification of the notion of convergence in economic research takes on a more narrow meaning, as scientists and economists deepened in problems of matching the levels of production of the poor and rich countries.

Given the fact that the regional integration processes between the individual countries of the world are characterized by varying degrees of depth and speed, a comprehensive analysis of these processes is a priority phenomenon that requires study and description. In the scientific economic literature there is no unified approach to the definition of key indicators, indices and measurement criteria of economic convergence [1]. Nearly unexplored remain problems of economic convergence of Ukraine with the European economic area.

Main body. To ensure the stability of the eurozone, were laid down a series of conditions for a legal and institutional nature, as a priority prerequisite for EU accession was the performance of the countries of the stability requirements, stipulated by Maastricht agreement. These requirements apply to such an important component, as economic convergence.

The Maastricht agreement defines the following criteria of economic convergence:

– achieving the appropriate level of price stability. The inflation rate in the country – a potential member of the European Union for the year preceding the year of inspection, is not more than 1.5% exceed the average inflation in the three countries of the European Union with the lowest indicators of inflation;

– ensure proper condition of financial performance in the long term period in order to prevent excessive budget deficits and excessive public indebtedness. The country's budget deficit should not be more than 3% of GDP (referentnand, that is, the maximum permissible value). In according with article 104c of Maastricht Agreement requirement may be considered executed when the level of the deficit exceeds the reference value, but for the last time relentlessly closer to it and when verifying almost reached the mark of 3%;

– avoiding excessive public debt and, that is, the ratio of the actual government debt to GDP should not exceed the reference value of debt (60% of GDP). This condition, according to the Maastricht agreement, can also be considered executed when debt levels exceed the reference value, but over recent years relentlessly continually approaching to it and the time the test almost reached the Mark of 60%;
– etc. [20].

Can today's professionals and analysts say that at least one of the above indicators Ukraine has reached convergence, or comes close to it? Despite the fact that the Government with the «pride» declares economic growth in 2016, and predicts a further revival of the national economy, a situation that has prevailing today into real sector shows otherwise.

We share the opinion of T. Kovalchuk that one of the important and effective factors that led to the current problems is the psychology of temporality, which is governed by big business, and virtually all Governments. The history of the Ukrainian Government, and, consequently, the power rotation is the confirmation of this [21]. Firmly realizing its time, every syllable of the Ukraine Government ask for loans to international organizations, willingly participates in debt, knowing that it’s return will be trying to resolve the following command.

We are not against such a policy of borrowing only if funds aimed at investment projects, in capital investments, the development of industry, agriculture, social sphere. However, almost all the funds of the foreign currency loans are used for current needs and replenishment of reserves of the NBU.

Purpose of the article. Based on the foregoing, the terms of management put forward the objective necessity of the study of the factors that hinder the economic convergence of Ukraine with the standards of the leading developed countries, particularly in Europe.

Retrospective analysis of economic literature revealed the lack of a unified approach to the theoretical substantiation of the essence of the concept of «convergence». In economic theory for the first time this concept appeared in the 1940s-1950s, and was borrowed from natural history, theory of systems where, due to the emergence of a relatively distant groups of organisms are common features in building and functions as a result of vital activity of these organisms in similar environmental conditions. The most common is considered there, which used the word «approach», «similarity» or «becoming like» that used during the analysis of the socio-economic area countries [16].

Assessing the degree of approximation of the economies, using the concept of real and nominal convergence. The first is determined by score of the real GDP per capita, the second is a set of indicators Maastricht agreement in which we have been described above.

Despite the fact that some researchers do not consider these indicators as universal and see in them a number of shortcomings, we can perform a comparative analysis of the indicators of Ukraine and determine whether there are signs of economic convergence of Ukraine and the European Union.

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Author's hypothesis is that the negative impact on the state of the national economy have not so much economic or political factors, but latent character factors. To confirm the hypothesis will use dynamic methods and comparative analysis, Pareto, expert assessments.

The results of the study. Known the fact that the material basis of the circularity is physical upgrades core capital, although the immediate impetus for the crisis can be a variety of reasons, and above all, monetary and credit turmoil. Although these shocks also is a consequence, not the cause of the prolonged crisis in the economy. A striking proof of this author's position is the economic situation in Ukraine, a strong impact on the status of any putting internal risks associated mainly with military actions in Donbas. This leads to the need of increasing cost of funding for law enforcement agencies, the restoration of damaged infrastructure, the housing sector, more. But there are also other factors that are, rather, latent in nature, and so – are more threats for Ukrainian society and hinder the economic convergence with developed countries, because they are difficult to detect and evaluate.
Yes, huge rate increases debt dependence, while the volumes of industrial production are reduced and almost missing the growth of GDP. In support of this we give the following statistics. The total amount of State and guaranteed debt over the last three years has 3,5 times (from 549.46 UAH billion in 2013 , up to 1941,36 billion UAH ($ 71.76 billion.) in the 2017 year), including State external debt during this period increased in 4.7 times and amounted to 977,64 billion UAH ($ 36.48 billion.) [21].

But, same public debt growth in itself does not cause apprehensiveness if the economy works, develops its real sector and is GDP. The results of the comparative analysis of public debt and GDP indicate, unfortunately, that the level of debt security almost twice exceeded the legal limit of the indicator «national debt/GDP», which not would exceed the 60% because the size of real GDP in 2016 amounted to 2034,43 billion UAH [22] ($ 75,35 billion) and, the ratio of the «national debt/GDP», respectively – 95,4 %.

It should be noted the special «objectivity» of the Ukrainian statistics. Until 2015, real GDP was equal to the price in 2010, and the results of the 2015 this figure was equal to the price of 2014, in 2016 – the prices of 2015. Instead declared by the World Bank falling in GDP of Ukraine in 2015 at 10% (according to the CIA – 11%) for statistics of Ukraine this figure has increased by almost 35%, and in 2016 – 1%! And while statistics (as a rule) do not correspond to the real numbers, but on their basis one could argue that when the adjustment of the ratio of national debt of Ukraine's real GDP exceeds the recommended 60% in 1,6 times. The comments here are unnecessary. The main creditor of Ukraine – IMF predicted increase Ukraine's GDP in 2016 to 2% with inflation at 12%. And although this prediction (for statistics!) almost fulfillment, you should ask yourself is it good or bad for the national economy , and which levers are able to positively affect on the way out of the protracted crisis, and on the formation of fundamentally new national paradigm of economic relations in the Ukrainian society? Analysis showed that the most critical to the national economy of Ukraine are the following factors:

– the growth of the public debt and of exceeding his pace over the pace of GDP;
– the excess of the share of foreign loans to cover budget deficit in 7 times;
– a reduction of 11% of GDP (in the ranking, compiled by the CIA, Ukraine on the growth of GDP was ranked in 2015: 222-nd position of 225 countries [23];
– significant amounts of shadow economy, the extent of which are not decreasing (table 1).

Table 1 The scale of the shadow economy in Ukraine in% of GDP

	Period								
	1989	1992	1995	2007	2011	2013	2014	2015	1 quarter of 2016
The share of the shadow economy to GDP	12.0	33.6	48.9	54.9	34	35	42	40	41

For comparison, according to the research of Frederick Shneider, the average size of the shadow economy in Europe in 2015 amounted to 18% of GDP. The lowest share of the shadow economy in GDP traditionally is observed in Switzerland (6.5%), Austria (8.2%), Luxembourg (8.3%), the Netherlands (9%) and the United Kingdom (9.4%). In Germany this index estimated at 12.2% of GDP [23].

[The scale of the shadow economy in post-socialist countries (in% of the country's GDP) was calculated by the method of D. Kaufmann-A. Kaliberda and by the method of M. Lasko]

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The results of the World Economic Forum's 2016 – 2017 according to the global competitiveness index Ukraine ranks 85 place with 138 countries were evaluated (table 2) [26].

Table 2 Competitiveness of Ukraine in the world

The index of global competitiveness (the position of Ukraine on the main components)	Years						
	2014-2015 (144 countries)	2015-2016 (140 countries)			2016-2017 (138 countries)		
	index	index	increase ↑ / decrease ↓		index	increase ↑ / decrease ↓	
			nominal	real		nominal	real
Institutions	130	130	-	↓	129	↑	↓
Infrastructure	68	69	↓	↓	75	↓	↓
Macroeconomic environment	105	134	↓	↓	128	↑	↑
Health care	82	82	-	↓	83	↓	↓
Higher education and professional training	40	34	↑	↑	33	↑	↑
The efficiency of market	112	106	↑	↑	108	↓	↓
The efficiency of the labour market	80	56	↑	↑	73	↓	↓
The development of financial market	107	121	↓	↓	130	↓	↓
Technological readiness	85	86	↓	↓	85	↑	↓
Compliance with the requirements of the modern business	99	91	↑	↑	98	↓	↓
Innovation	81	54	↑	↑	52	↑	↑

The real importance of change of the index of global competitiveness is defined taking into account the number of countries, which have been evaluated.

The table shows that in global competitiveness index Ukraine improved its position in terms of «higher education and vocational training, «innovation», but rapidly reduces its position on the indicator of the development of the financial market».

This is due to the ineffective policy of NBU, the lack of reforms in the field of development of non-government pension provision, underdevelopment of the Ukrainian stock market, etc., but confirms the fact that Ukraine has significant intellectual potential, which, unfortunately, not valued and not supported by the State and big business. In addition, the reforms that are necessary on the path of convergence, slowed or are one-sided nature. So, in our opinion, the Ukrainian Government uses just destructive measures, without trying to hold back or smooth economic and social shocks that accompany these actions. For example, the gradual withdrawal of energy tariffs to the European level is not justified economically, because the main energy supply companies with funds not updated during Soviet times, and wear the networks supply exceeds 80%.

Another step of the Ukrainian Government to the convergence was the termination of government regulation and actually control the formation of consumer prices for food, medicines, and other socially important products. Dropped the concept of «maximum ROI», limiting the level of allowances. Consequently: oligarchic group retail chains of hypermarkets, which actually form a private monopoly formations, acting in concert when setting prices. Antimonopoly Committee thus detects inactivity, which can also qualify as a destructive latent management. This has led to the arbitrary increasing prices of the most popular food: bread is at 47%, pasta – 49%, fish – 51%, fruits, vegetables – 67%,

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utilities increased three times, medical – almost double. For the six years the life of average Ukrainians increased by 80%, and real income has decreased more than 10% [27].

In earlier publications we justify conceptually economic model of national economy of Ukraine, which would be satisfied with the economic interests of the majority of citizens and society in general [24, 25]. We defined components of a successful economy:

1) information and informatization;
2) intellectual capital;
3) availability of resources.

We considered those three components, using philosophical concepts and Pareto principle. Grounded presence of deregulation of these components of a successful economy in the Ukrainian society.

This disbalance leads to negative consequences in the Ukrainian society, which hinder the economic convergence. Namely:

1) in Ukrainian society perceive information, interpret it, have access to information sources and technologies. Result: information - weightiest arms control community;

2) level of intellectualization of the human capital and the desire for continuous self-improvement and self-education. Consequence: the ease of managing the crowd with a low intellectual level, are not able to have their own opinion and position;

3) in access to resources and other economic and social benefits. For the Ukrainian society a disbalance in the access to material resources and goods is 90:10. The consequence is the stratification of society on the rich and the poor, the almost complete destruction of the «middle class».

These patterns have spawned two big problems in Ukraine: 1) politicized oligarchy; 2) passive behavior of the participants of economic relations. These problems are disease of the Ukrainian society and latent factors containment of economic convergence in the European region. Because these imbalances by Pareto are causes of mass diseases of mankind, that little investigated, but because scientists have not yet classified, and thus – the diagnosis is not represented in the timeline of medical diseases.

The question arises: is it possible to overcome these «diseases» in the body of the national economy, which we have identified as «passive behavior of the participants of economic relations through ignorance» and «politicized oligarchy»? the answer is simple, and it's a lot of talk, but few do. Known ancient folk wisdom: Everybody wants to change the world, but no one wants to start with yourself! Declare can be beautiful and a lot. But nothing will change until every member of the Ukrainian society (top - down) do not realize that changes need to start with yourself. Then will appear in those who have the opportunity to do real economic reforms that would have made Ukraine a successful, prosperous country, contributed to the real economic convergence of Ukraine with the developed countries of the European Union.

The conclusions and prospects of further development. Consideration of the problems that hinder the economic convergence of Ukraine with the European region has reached conclusions on the need to development and implementation of the state accommodative policy, aimed not at the exacerbation of social tension in the Ukrainian society and deepening of the economic crisis, but to mitigate the shock effects, due to convergence processes. In this context Ukraine must take into account the relevant experience of the countries of EU and apply the most effective tools of convergence and measures shock against state regulation, in particular, such as:

– building export capacity and activation of foreign trade;
– software innovative restructuring of the economy in general and the sphere of employment in particular;
– the increase of the educational qualification level of labour resources and the formation of favourable conditions for creative implementation of scientific and innovation on the Ukrainian markets, stopping the outflow of intellectual capital;
– ensure strict control over the use of international organizations funds in the economic development of the sectors of the national economy, the structural changes in the economy, creating innovative, energy-efficient industries and new jobs;
– take structural measures for bringing the economy to separate government from business;
– the formation of a new national paradigm of social and economic responsibility to the society, which is based on the principles of corporate culture and ethics in civil and economic relations.

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SUSTAINABLE CONSTRUCTION – USE OF MASONRY DEMOLITION WASTE IN CONCRETE

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ABSTRACT

Massive amounts of brick waste are obtained from demolition of old buildings and structures around the world. With the increased stress on sustainable construction, and environmentally friendly materials and greener concreting practices, a large proportion of such waste bricks are crushed and mixed with normal aggregates for use in concrete. The performance of concrete containing waste brick aggregates partially replacing normal aggregates have not been investigated for their performance. This paper covers investigations carried out on concrete with such aggregates obtained from demolition waste and mixed with varying proportions of normal aggregates to produce concrete. Two types of crushed brick aggregates were mixed with gravel in the ratios of 30:70 and 40:60 by weight and specimen were cast for investigations. Two w/c ratios were investigated. Various tests were carried out to assess the compressive strength of cubes and cylinders of mixed aggregates concrete along with f1exural strength, stress/strain behavior, moduli of elasticity, ultrasonic pulse velocity determination, densities, surface absorption, shrinkage and frost resistance. The values obtained from these tests were compared with the values of concrete with normal aggregates (gravel) with similar w/c ratios. While the strength tests and durability tests more or less gave satisfactory results however the larger moisture absorption by the waste brick aggregates reduces the frost resistance capacity somewhat thereby care needs to be exercised in using these mixes in regions/ areas susceptible to frost.

Keywords: Demolition waste, construction waste, recycled aggregates, recycled aggregates concrete, sustainable construction, environmental friendly waste, green concrete.

INTRODUCTION

Huge amounts of demolition waste were generated in the world wars. After the Second World War, Germans were the first ones to initiate research on use of waste materials in construction. Massive efforts have gone in research on disposal/ recycling of waste products being generated through various processes. Explorations of possible usage of such wastes in various industries have been carried out extensively. Shortage of development budgets in developing/ under developed countries forces them to make efforts to find cheaper substitutes that are locally available. Furthermore, most of the masonry construction which was built years ago have already outlived their lives and are being demolished thereby creating large quantities of waste brick. Crushed brick aggregates from bricks obtained from demolition/ construction waste are usually added to normal aggregates and used for concreting in many countries however, there has been no information nor research on the performance of such concrete in which normal aggregates have been partly replaced with crushed waste brick aggregates exists in literature neither any information on acceptable percentages of such waste aggregates to be used in various concrete mixes are evaluated, to keep the resulting concrete properties acceptable, though concrete with 100% crushed brick aggregates have been investigated[1-8].

RESEARCH SIGNIFICANCE

The significance of this research is to investigate the properties of concrete made from partial replacement of natural aggregates in various proportions with abundantly available masonry construction waste from demolition of masonry construction and its use in quality concrete along with requisite care to be practiced in use of such concretes.

CONCRETE MIXES USED FOR EXPERIMENTAL TESTING

To investigate the performance of concrete with normal aggregates replaced with a percentage of crushed waste brick aggregates, two sets of specimens were prepared for experimental investigation by replacing 30% and 40% by weight of gravel aggregate with crushed waste brick coarse aggregates. The w/c ratios of two characteristic strengths of 35 and 50N/mm2 of concrete with gravel were investigated for concrete with mixed gravel and crushed waste brick aggregates. The concrete specimens used as standard to carry out comparative study were prepared by using Thames Valley gravel as coarse aggregates. Water/ cement ratio, quality of water, curing conditions and test methods were kept constant for all specimen. Table 1 gives the quantities per cubic meter of concrete. Table 2 and 3 give the properties of concrete with mixed aggregates.

Table 1. Quantities per cubic meter of concrete

MIX W/C RATIO	11 0.5	12 0. 385	21 0. 5	22 0.385
Density (average)kg/m^3	2330	2355	2345	2360
Cement kg/m^3	320	415	320	415
Water kg/m^3	160	160	160	160
Fine aggregate kg/m^3	575	535	59F	535
Coarse aggregate	1275	1245	1270	1250
w/c ratio	0.5	0.385	0.5	0.385

MIX W/C RATIO	31 0.5	32 0.385	41 0.5	42 0. 385
Density (average)kg/m3	2305	2325	2315	2330
Cement kg/m3	320	415	320	415
Water kg/m3	160	160	160	160
Fine aggregate kg/m3	570	525	585	525
Coarse aggregate kg/m3	1255	1225	1250	1230
w/c ratio	0.5	0.385	0.5	0.385

Table 2. Properties of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	COMPRESSIVE STRENGTH		CYLINDER STRENGTH N/mm2	FLEXURAL STRENGTH N/mm2	ELASTIC MODULUS DYN N/mm2	ELASTIC MODULUS STATIC N/mm2
		7DAY N/mm2	28DAY N/mm2				
11	0.5	34.00	39.30	29.02	6.46	37902.1	14790.3
12	0.385	48.10	53.24	32.65	7.50	39968.7	18226.5
21	0.5	33.21	37.14	29.33	7.58	40508.1	14660.4
22	0.385	47.33	52.43	31.76	8.17	39057.2	15172.9
31	0.5	34.73	40.31	27.84	6.13	36992.4	13322.7
32	0.385	47.81	52.74	30.71	6.97	38163.7	16269.6
41	0.5	35.66	41.00	27.22	7.61	38676.9	14500.0
42	0.385	42.93	50.87	32.69	7.73	37597.6	14672.1
Gravel	0.385	36.83	41.34	29.3	4.41	46922.8	23480.2
	0.5	46.49	53.81	37.98	5.33	47557.8	24033.5

Note:

a. 11 - 30% London brick aggregate + 70% Gravel
b. 12 - 30% London brick aggregate + 70% Gravel
c. 21 - 30% Sand lime brick aggregate + 70% Gravel
d. 22 - 30% Sand lime brick aggregate + 70% Gravel
e. 31 - 40% London brick aggregate + 60% Gravel
f. 32 - 40% London brick aggregate + 60% Gravel
g. 41 - 40% Sand lime brick aggregate + 60% Gravel
h. 42 - 40% Sand lime brick aggregate + 60% Gravel

EXPERIMENTAL TESTING REGIME

Testing regime followed is given below. Four sets of specimen from four different batches were used in all tests:

Compressive strength/density	150mm cubes, 150mm Diameter, 300mm long cylinders.
Flexural strength/Shrinkage	150x150x750mm beams.
Stress/strain behavior	150mm diameter, 300mm long cylinders.
Static modulus of elasticity	150mm diameter, 300mm long cylinders.

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Dynamic modulus of elasticity	150x150x750mm beams.
Ultrasonic pulse velocity	150mm cubes.
Initial surface absorption	150mm cubes.
Shrinkage	150mm cubes.
Frost Resistance	150mm cubes.

All specimen were cured in water at 20^0 C for 42 days before testing.

EXPERIMENTAL TESTING RESULTS

Results obtained from testing of various test samples are summarized below and are also shown in Tables 3 to 17.

Table 3. Properties of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	DENSITY OF CONCRETE (kg/m3)		ISAT	SHRINKAGE $*10^{-4}$ mm	PULSE VELOCITY km/s
		dry	saturated			
11	0.5	2219	2330	Average	3.024	4.279
12	0.385	2276	2363	low	3.73	4.273
21	0.5	2271	2353	low	2.68	4.109
22	0.385	2289	2377	low	3.268	4.230
31	0.5	2184	2297	Average	3.42	4.012
32	0.385	2231	2312	low	3.81	4.103
41	0.5	2227	2314	low	3.01	3.9g4
42	0.385	2243	2331	Low	3.63	4.112
Gravel	0.5 0.385	2403 2411	2454.80 2457.70	Low Low	1.17 2.97	4.76 4.79

Compressive strength

Compressive strength tests on cubes at 7 days and 28 days showed that the rate of development of strength of mixed aggregate concrete was similar to normal aggregate concrete.

Specimen with 30% and 40% of gravel replaced by coarse crushed waste construction brick and waste sand lime brick aggregates developed satisfactory compressive strengths at the first attempt.

On testing cylinders for 28 days compressive strength, it was observed that the cylinder strength varied from 58 to 78% of cube strength as compared to 60 to 67% for gravel. Table 4 gives the 28-day compressive strengths of cubes and cylinders for concrete with different percentages of brick and gravel mixed aggregates concrete.

Table 4. Cube and cylinder strengths of different concretes

TYPE OF MIX	W/C RATIO	CUBE STRENGTH N/mm2	CYLINDER STRENGTH	
			N/mm2	%
11	0.50	39.30	29.02	73.84
12	0.385	53.24	32.65	61.33
21	0.50	37.14	29.33	78.97
22	0.385	52.43	31.76	60.58
31	0.50	40.31	27.84	69.06
32	0.385	52.74	30.71	58.23
41	0.50	41.00	27.22	66.39
42	0.385	50.87	32.69	64.26
Gravel	0.50	41.34	25.17	60.90
Gravel	0.385	53.81	36.3 7	67.60

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Flexural strength

l50*150*750mm beams were cast for determining the flexural strength of concrete with brick plus gravel aggregates mixed in the ratio of 30:70 and 40:60 respectively, vide BS 1881: Part 109: 1983. Test beams were cured for 28 days before testing. The tests for flexural strength was carried out vide BS 1881: Part 118: 1983 with third point loading. Table 5 gives the values of flexural strength against average compressive strength of concrete with mixed aggregates.

It was observed that the flexural strength of concrete with mixed aggregates varied from 6.1 to 7.7 N/mm^2 i.e. 15 to 20% of the 28 day compressive strength as compared to flexural strengths varying from 4.4 to 5.3 N/mm^2 i.e. 9.9 to 10.7% of the 28 day compressive strengths for gravel concrete. Hence flexural strength values for concrete with mixed aggregates are 7% higher on average than concrete with Thames Valley gravel.

Table 5 shows the variation in flexural strength of mixed aggregates concrete as compared to brick aggregate concrete and gravel concrete. It can be observed from Table 5 that flexural strength of concrete with brick aggregates is slightly lower than gravel concrete. The flexural strength of concrete with mixed aggregates is higher than both brick aggregate concrete as well as gravel concrete.

Table 5. Flexural strength of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	COMPRESSIVE STRENGTH 28DAY N/mm2	FLEXURAL STRENGTH N/mm2
11	0.5	39.30	6.46
12	0.385	53.24	7.50
21	0.5	37.14	7.58
22	0.385	52.43	8.17
31	0.5	40.31	6.13
32	0.385	52.74	6.97
41	0.5	41.00	7.61
42	0.385	50.87	7.73
Gravel	0.5 0.385	41.34 53.81	4.41 5.33

It was observed that failure in flexure across the section of test beams occurred by a crack through the mortar, through the brick aggregate particles and around the gravel particles in case of concrete with brick aggregates plus gravel whereas the failure crack propagated through the mortar and around the gravel particles in the case of the control mix with Thames valley gravel as coarse aggregate. No gravel particles were observed to fail but failure occurred along the bond surface between the mortar and rounded gravel particles.

Stress/strain behavior

Static modulus of elasticity

150mm diameter, 300mm long cylinders were prepared for determining the static modulus of elasticity in compression. Strains were recorded for every incremental load increase. Table 6 gives the values of static modulus of elasticity for concrete with mixed aggregates.

The average static modulus of elasticity was observed to vary between 60 and 75% for concrete with crushed brick and gravel aggregates mixed in the ratio of 30:70 respectively and between 54 and 66% for concrete with crushed brick and gravel mixed in the ratio of 40:60 respectively, as compared to concrete with gravel aggregates only.

The values of static modulus of elasticity were observed to increase with increase in the compressive strength of concrete. The average static modulus of elasticity for concrete with brick aggregate plus gravel in the ratio 30:70 respectively is 37% lower as compared to concrete with Thames Valley gravel whereas concrete with brick aggregates plus gravel in the ratio of 40:60 respectively is 41% lower. The reduction in static modulus of elasticity of concrete with mixed aggregates is due to lower modulus of elasticity of normal construction brick and sandlime brick aggregate.

Table 6. Static modulus of elasticity of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	COMPRESSIVE STRENGTH 28DAY N/mm2	STATIC MODULUS OF ELASTICITY N/mm2
11	0.5	39.30	14790.3
12	0.385	53.24	18226.5
21	0.5	37.14	14660.4
22	0.385	52.43	15172.9
31	0.5	40.31	13322.7
32	0.385	52.74	16269.6
41	0.5	41.00	14500.0
42	0.385	50.87	14672.1
Gravel	0.5	41.34	23480.2
Grave	0.385	53.81	24033.5

Dynamic modulus of elasticity

Test beams 150*150*750mm were cast for carrying out the dynamic modulus of elasticity tests. The specimens were cured for 28 days before testing for dynamic modulus of elasticity. Table 7 gives the values of dynamic modulus of elasticity for concrete with mixed aggregates.

Table 7. Dynamic modulus of elasticity of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	COMPRESSIVE STRENGTH N/mm2	DYNAMIC MODULUS OF ELASTICITY
11	0.5	39.30	37902.1
12	0.385	53.24	39968.7
21	0.5	37.14	40508.1
22	0.385	52.43	37597.6
31	0.5	40.31	36992.4
32	0.385	52.74	38163.7
41	0.5	41.00	38676.9
42	0.385	50.87	39057.2
Gravel	0.5 0.385	41.34 53.81	46922.8 47557.8

The average resonant frequencies observed for concrete with normal construction brick aggregate plus gravel and sandlime brick aggregate plus gravel were observed to be about 9 to 10% and 8 to 9% lower than for concrete with Thames Valley gravel aggregate only with an average value of 2981Hz.

The dynamic modulus of elasticity for concrete with normal construction brick aggregate plus gravel varied from 36992 to 38l63N/mm2 whereas that for concrete with sandlime brick aggregate plus gravel varied from 37597 to 40508N/mm2. Values of dynamic modulus for concrete with Thames Valley gravel aggregate varied from 46922 to 47557N/mm2. Hence the average dynamic modulus for concrete with normal construction brick aggregate plus gravel and sandlime brick aggregate plus gravel is 77 and 80% respectively of the value for concrete with Thames Valley gravel aggregate. The reduction in dynamic modulus of elasticity of concrete with mixed aggregates is due to lower resonant frequencies and lower densities of crushed brick aggregates.

Ultrasonic pulse velocity

Ultrasonic pulse velocity tests for observing the velocity of pulses across the mixed aggregate concrete specimen were carried out as per BS 1881: Part 203: 1986. 150mm cubes were cured for 28 days as per BS 1881: Part 111: 1983 before testing for the pulse velocity. Pulse velocities observed for different concretes are given in Table 8.

Table 8. Ultrasonic pulse velocities of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	COMPRESSIVE STRENGTH N/mm2	PULSE VELOCITY Km/s
11	0.5	39.30	4.279
12	0.385	53.24	4.273
21	0.5	37.14	4.109
22	0.385	52.43	4.230
31	0.5	40.31	4.012
32	0.385	52.74	4.103
41	0.5	41.00	3.984
42	0.385	50.87	4.112
Gravel	0.5 0.385	41.34 53.81	4.76 4.79

Average pulse velocity across concrete with normal construction brick aggregate plus gravel was observed to be 4.27km/s for aggregate ratio of 30:70 respectively and 4.05km/s for the aggregate ratio of 40:60 respectively for average values of static moduli of elasticity of 16508N/mm2 and 14796N/mm2 dynamic moduli of elasticity of 38935 and 37577N/mm2 respectively. similarly, the average pulse velocity with sandlime brick aggregate plus gravel was observed to be 4.15km/s for aggregate ratio of 30:70 respectively and 4.0km/s for the aggregate ratio of 40:60 respectively for average values of static moduli of elasticity of 14916 and 14585N/mm2 and dynamic moduli of elasticity of 39052 and 38866N/mm2 respectively. For concrete with Thames Valley gravel as coarse aggregate, average pulse velocity was observed to be 4.8km/s for average values of static modulus of elasticity of 23757N/mm2 and dynamic modulus of elasticity of 47240N/mm2. Hence the variation of pulse velocity in the case of concrete with normal construction brick aggregate plus gravel in the ratios 30:70 and 40:60 is 11 and 15.5% lower, respectively, as compared to concrete with gravel. Concrete with sandlime brick waste aggregate plus gravel in the ratios 30:70 and 40:60 have been observed to have pulse velocities 13.5 and 16.5% lower, respectively, as compared to pulse velocity in concrete with Thames Valley gravel aggregate. It was observed that pulse velocities, static moduli and dynamic moduli of elasticity obtained from experimental investigations did not correlate with the values given in BS 1881: Part 203: 1986 for concrete with different types of brick aggregates mixed with gravel aggregates in different percentages. Figure 6 shows the variation in pulse velocity of mixed aggregates concrete from brick aggregate concrete to gravel concrete.

Table 9. Comparison of empirical and experimental moduli of elasticity by pulse velocity measurements

Type of Mix	Pulse Velocity Km/s	Empirical Moduli Static Dynamic N/mm2		Experimental Moduli Static Dynamic N/mm2	
11	4.3	24500	34000	14790	37902
12	4.3	24500	34000	18226	39968
21	4.1	20000	30500	14660	40508
22	4.2	22000	32000	15173	37597
31	4.0	18000	29000	13322	36992
32	4.1	20000	30500	14660	40508
41	3.98	18000	29000	13322	36992
42	4.1	20000	30500	14660	40508
Gravel 0.5 0.385	4.76 4.79	30500 43000	39000 49000	23480 24033	46923 47558

Initial surface absorption (ISAT)

ISAT tests were carried out on cubes as per BS 1881: Part 5: 1970. The results were compared with the typical results of ISAT tests given by Concrete Society Technical Report No.3l.

ISAT results obtained from tests on concrete with normal construction brick aggregates plus gravel mixed in the ratios

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30:70 and 40:60 respectively, revealed that surface absorption was average and almost 50% higher amounts of water were absorbed in both cases as compared to concrete with gravel and w/c ratio of 0.50. The absorption was, however, similar to concrete with gravel, for w/c ratio of 0.385. Low surface absorption was observed for concrete with sandlime brick aggregates plus gravel in the ratios of 30:70 and 40:60 for w/c ratios of 0.385 & 0.5 similar to concrete with gravel only.

Shrinkage

Shrinkage tests were carried out in accordance with RILEM Recommendation CPC 9 - Measurement of shrinkage and swelling. 100*100*500mm prismatic specimen were cast and cured in water at 20° C for 28 days. The prisms were then accurately measured and stored at 20°c and 65% relative humidity for ninety days after which they were measured accurately to observe the shrinkage values. Table 11 gives the shrinkage of concrete with mixed aggregates.

Shrinkage of concrete with normal construction brick waste aggregates plus gravel in the ratio of 30:70 was almost one and a half times higher than concrete with gravel only for w/c ratio of 0.50, whereas for w/c ratio of 0.385, shrinkage was 25% higher. For the ratio of 40:60 of normal construction brick aggregate and gravel respectively, shrinkage was observed to be twice the value of concrete with gravel only for w/c ratio of 0.50, whereas for w/c ratio of 0.385, shrinkage was observed to be about 30% higher than concrete with gravel only.

Shrinkage of concrete with Sandlime brick waste aggregates plus gravel in the ratio of 30:70 was almost one and a quarter times higher than concrete with gravel only for w/c ratio of 0.50, whereas for w/c ratio of 0.385, shrinkage was about 10% higher. For the ratio of 40:60 of sandlime brick waste aggregate and gravel respectively, shrinkage was observed to be twice the value of concrete with gravel only, for w/c ratio of 0.50 whereas for w/c ratio of 0.385, shrinkage was observed to be about 22% higher than concrete with gravel only.

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Frost Resistance

The RILEM recommendation on methods of carrying out and reporting freeze thaw tests on concrete without deicing chemicals were followed to carry out an investigation on the comparative performance of concrete with different types of coarse brick waste aggregates and Thames Valley gravel. 100*l00*500mm prisms were cast and cured for 28 days in water at 20°C before subjecting them to freezing and thawing cycles. One specimen of each strength was cast with two thermistors at the center so as to monitor the temperature of specimen during the test. Length change and variation in dynamic modulus were monitored during the test and the residual compressive strength of each specimen recorded at the end of the test. Table 12 gives a summary of the performance of mixed aggregates concrete in frost resistance test. Table 13 gives the comparison of compressive strengths of dummy specimens and specimens of frost resistance test after completion of 50 cycles of freezing and thawing. Concrete with normal construction brick waste aggregate plus gravel mixed in the ratios of 30:70 and 40:60 respectively, both started expanding continuously on cyclic freezing and thawing and the large expansions were accompanied by a rapid decrease in dynamic modulus, as shown in Tables14 and 10.15. The dynamic modulus decreased by almost 20% in the first twenty cycles after which the decrease was observed to be gradual for w/c ratios of both 0.50 and 0.385. Net reduction in dynamic modulus after fifty cycles was observed to be 23.7 and 28.46% for w/c ratio of 0.50 against 7.33% for concrete with Thames Valley gravel. The associated maximum increase in length was 0.073% and 0.076% as compared to a decrease in length of 0.048% for concrete with Thames Valley gravel.

For w/c ratio of 0.385, the reduction in dynamic modulus was observed to be 24.13 and 28.53% respectively for ratios of 30:70 and 40:60 of normal construction brick aggregate and gravel in concrete. The reduction in dynamic modulus of concrete with Thames Valley gravel with similar compressive strength was observed to be 14.39%. The corresponding increase in length was observed to be 0.035 and 0.068% compared to 0.071% for concrete with Thames Valley gravel. Concrete with normal construction brick waste aggregate plus gravel showed continuously increasing expansions for the first thirty cycles of freezing and thawing. Concrete with normal construction brick waste aggregate and gravel in the ratio of 40:60 respectively (by weight) showed larger expansions as compared to concrete with normal construction brick waste aggregate and gravel in the ratio of 30:70 respectively. The large increase in length and accompanying rapid reduction in dynamic modulus is due to the continuous expansion of normal construction brick aggregates which have high absorption of about 20% and comprise of large sized pores with higher quantity of freezable water. Since the specimens were fully saturated on start of testing, expansion of water in the aggregates on freezing pressurizes excess water out of the aggregate into the surrounding mortar. On further cooling, this water expands and exerts dilative pressures on the mortar resulting in microcracking within the mortar, along the bond surface between mortar and aggregate particles and also within the aggregate particles. The situation is worsened by the differential expansion/contraction between the brick aggregates, mortar and gravel particles hence cyclic freezing and thawing increases microcracking thereby resulting in loss of strength along with length increases.

The length of specimen increased continuously over the first thirty cycles after which there was slight decrease in length in the next ten cycles after which again the length started increasing. This behavior is possibly due to the presence of a few closed pores in brick aggregate which were not open initially. The expansion over the first thirty cycles of freezing and thawing exerted sufficient pressure on these pores to open up and provide some relief for the excess water to be accommodated. After some excess water was accommodated in these pores, the specimen showed slight contractions for the next ten cycles after which the specimen again started increasing in length. The behavior of concrete with normal construction brick waste aggregates plus gravel is entirely different from concrete with Thames Valley gravel only. Concrete with Thames Valley gravel shows slight contraction in the first twenty cycles after which there is a slight increase in length. The corresponding reduction in dynamic modulus is gradual. Concrete with normal construction brick waste aggregate plus gravel shows large expansions in first thirty cycles with a large reduction in dynamic modulus. Thereafter the expansions are small and continuous along with a gradual decrease in dynamic modulus. Table 13 shows the variation in compressive strength of the dummy specimen and of the specimen after fifty cycles of freezing and thawing. Concrete with normal construction brick waste aggregates plus gravel in the ratio of 30:70 by weight respectively shows a variation of 3.33 to 3.53% for w/c ratios of 0.50 and 0.385, respectively. For concrete with ratio of normal construction brick aggregate and gravel of 40:60 respectively, the variation in compressive strength is 4.18 to 4.39% for w/c ratios of 0.50 and 0.385, respectively. Concrete with Thames valley gravel shows a variation of 1.02 to 1.3% for w/c ratios of 0.50 and 0.385 respectively. Hence the reduction of compressive strength for concrete with normal construction brick waste aggregate plus gravel in the ratio of 30:70 by weight respectively is three times and for the ratio of 40:60 by weight respectively is four to four and a half times as compared to concrete with Thames Valley gravel only.

Tables 16 and 17 gives the performance of sandlime brick waste plus gravel aggregate concrete in frost resistance test. For concrete with sandlime brick waste aggregate plus gravel mixed in the ratios of 30:70 and 40:60 respectively, the reduction in dynamic modulus after fifty cycles was observed to be 15 and 14.8% for w/c ratio of 0.50 against 7.33% for concrete with Thames Valley gravel. The associated maximum increase in length was 0.06 and 0.057% as compared to a decrease in length of 0.048% for concrete with Thames Valley gravel. For w/c ratio of 0.385, the reduction in dynamic modulus was observed to be 3 and 5.7% respectively for ratios of 30:70 and 40:60 of normal construction brick aggregate and gravel in concrete. The reduction in dynamic modulus of concrete with Thames Valley gravel with similar w/c ratio was observed to be 14.39%. The corresponding increases in length were observed to be 0.036 and 0.046% compared to 0.071% for concrete with Thames Valley gravel.

Concrete with sandlime brick aggregate plus gravel behaved somewhat similarly to concrete with Thames Valley gravel. There was a slight contraction in the first ten cycles after which the specimen started expanding gradually until thirty cycles of cyclic freezing after which there was again a slight decrease in length over the next ten cycles followed by gradual expansion. This behavior is possibly due to the presence of a few closed pores inside the brick aggregates which open up on exertion of dilative pressures of cyclic cooling. The slight contraction later on is due to accommodation of some excess expanding water in these pores which open up after about thirty cycles. Later on, the specimen again starts expanding due to dilative pressures on cooling.

Table 10. Densities of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	DENSITY OF CONCRETE(kg/m3) Dry	Saturated
11	0.5	2219	2330
12	0.385	2276	2363
21	0.5	2271	2353
22	0.385	2289	2377
31	O.5	2184	2297
32	0.385	2231	2312
41	0.5	2227	2314
42	0.385	2243	2331
Gravel	0.5 0.385	2403 2411	2454.8 2457.7

The reduction in dynamic modulus in concrete with sandlime brick waste aggregate plus gravel is gradual and is one-third to half the value for concrete with Thames Valley gravel. The lower loss of strength is due to the fine pores present in sandlime brick aggregate which, although having an absorption of 10%, has little of freezable water. The expansion of brick aggregates could be similar to the expansion of mortar thereby reducing the micro cracking inside the concrete as compared to concrete with Thames Valley gravel only, thereby reducing the loss of strength. Concrete with sandlime brick waste aggregates plus gravel in the ratio of 30:70 by weight respectively shows a variation in compressive strength of 2.54 to 0.86% for w/c ratios of 0.50 and 0.385, respectively. For concrete with ratio of sandlime brick waste aggregate and gravel of 40:60 respectively, the variation in compressive strength is 2.39 to 1.43% for w/c ratios of 0.50 and 0.385, respectively. Concrete with Thames Valley gravel shows a variation of 1.02 to 1.3% for w/c ratios of 0.50 and 0.385, respectively

Table 11. Shrinkage of concrete with mixed aggregates

TYPE OF MIX	W/C RATIO	SHRINKAGE *l0-4 mm
11	0.5	3.024
12	0.385	3.73
21	0.5	2.68
22	0.385	3.268
31	0.5	3.42
32	0.385	3.81
41	0.5	3.01
42	0.385	3.69
Gravel	0.5 0.385	1.176 2.976

Table 12. Summary - Frost resistance test on concrete with mixed aggregates **(50 cycles)**

TYPE OF MIX	W/C RATIO	EXPANSION %	REDUCTION IN DYNAMIC MODULUS
11	0.50	0.04	23.7
21	0.50	0.06	15.0
31	0.50	0.076	28.4
41	0.50	0.057	14.8
12	0.385	0.035	24.1
22	0.385	0.036	3.0
32	0.385	0.068	28.5
42	0.385	0.046	5.7
Gravel	0.50 0.385	0.048 0.07	7.1 14.4

Table 13. Comparison of compressive strengths of concrete specimen before and after Frost Resistance Tests

TYPE OF MIX	W/C RATIO	INITIAL STRENGTH N/mm2	RESIDUAL STRENGTH N/mm2	VARIATION %
11	0.50	45.05	43.55	3.33
12	0.385	50.85	49.05	3.53
21	0.50	47.25	46.05	2.54
22	0.385	52.05	51.6	0.86
31	0.50	42.51	40.73	4.18
32	0.385	50.76	48.53	4.39
41	0.50	46.30	45.19	2.39
42	0.385	51.64	50.9	1.43
Gravel	0.50	41.34	40.32	1.02
Gravel	0.385	53.81	53.11	1.3

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Table 14. Performance of concrete with normal construction brick waste aggregate and gravel in the ratio of 30:70, respectively, in frost resistance

Sample No.11. 30% London brick + 70% Gravel W/C Ratio 0.50 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.0lmm)	248.25	258.5	271	285	266	268.5
Weight(g)	11870.5	11878	11877	11875	11877.5	11877
R frequency(Hz)	4131.5	3725.5	3721	3693	3641.5	3607.5
Dyn.Mod.(N/mm2}	40522.5	32963	32900	32425	31502.8	30920.4
Reduction in Dyn Modulus - 23.7%, Increase in length - 0.04% Sample No.12. 30% London brick + 70% Gravel W/C Ratio 0.385 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm)	255.25	261.7	273.5	286.5	271	273
Weight(g):	11919.5	11926	11926	11904	11874	11925.5
R frequency(Hz)	4104	3594.5	3627	3595	3585	3573.5
Dyn.Mod. (N/mm2)	40149.5	30807.7	31382	30847	30656	30462.5
Reduction in Dyn mod = 24.13% Increase in length = 0.035%						

Table 15. Performance of concrete with normal construction brick aggregate and gravel in the ratio of 40:60, respectively, in frost resistance test

Sample No.31. 40% London brick + 60% Gravel W/C Ratio 0.50 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.0lmm)	239	249	264	277	256	261
Weight(g)	11769	11774	11777	11778	11777	11778
R frequency(Hz)	4011	3523	3501	3483	3421.2	3391
Dyn.Mod.(N/mm2}	37868	28813	27781	27600	27377	27062
Reduction in dynamic modulus - 28.46% Increase in length = 0.044% (max 0.076%) Sample No.32. 40% London brick + 60% Gravel W/C Ratio 0.385 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm)	265	274	287	299	287	293
Weight(g):	11817	11821	11824	11828	11794	11801
R frequency(Hz)	4003	3491	3427	3415	3402	3382
Dyn.Mod. (N/mm2)	37871	28813	27781	27600	27377	27062
Reduction in dynamic modulus = 28.53% Increase in length = 0.056% (max 0.068%)						

CONCLUSIONS

The rate of development of strength of mixed aggregate concrete was observed to be similar to that of normal aggregate concrete. Mixed aggregates concrete developed satisfactory compressive strengths as compared to concrete with gravel aggregate. Flexural strengths were higher by about 5%, the average static modulus of elasticity was observed to decrease by 35 to 40%, and average dynamic modulus for concrete with brick aggregate plus gravel was 20 to 23% lower than the value for concrete with Thames Valley gravel aggregate. The variation of pulse velocity in the case of concrete with brick aggregate plus gravel is 7 to 13% lower as compared to concrete with gravel. Average densities for concrete with brick aggregates plus gravel were 4 to 6% lower than concrete with gravel. ISAT results obtained from tests on concrete with brick aggregates plus gravel showed that surface absorption was almost 50% higher for higher w/c ratio but was however similar to concrete with Thames Valley gravel, for lower w/c ratio. Shrinkage of concrete with brick aggregates plus gravel was almost one and a half times higher than concrete with gravel for higher w/c ratio whereas for lower w/c ratio shrinkage was 25% higher.

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Table 16. Performance of concrete with sandlime brick aggregate and gravel in the ratio of 30:70, respectively, in frost resistance test

Sample No.21. 70% Gravel + 30% Sandlime brick U/C Ratio 0.50 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.0lmm)	214.7	212.7	220	245	216	217.5
Weight(g)	11962	11966	11967	11967.5	11968	11968.5
R frequency(Hz)	4186	4012.5	3971.5	3926	3860.5	3859
Dyn.Mod.(N/mm2}	41931	38514.8	37742.8	36920	35656.8	35631.3
Reduction in dyn mod = 15% Increase in length = 0.005% (max 0.06%) Sample No.22. 70% Gravel + 30% Sandlime brick W/C Ratio 0.385 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm)	235.5	233.25	242	253.5	234.5	238
Weight(g):	11947.5	11949.5	11949	11949.5	11949	11947
R frequency(Hz)	4112	4064	4064.5	4063	4067.5	405
Dyn.Mod. N/mm2)	40402.9	39461.6	39485	39474.2	39337	39217
Reduction in Dyn mod - 3% Increase in length = 0.005% (max 0.036)						

Table 17. Performance of concrete with sandlime brick aggregate and gravel in the ratio of 40:60, respectively, in frost resistance test

Sample No.41. 60% Gravel + 40% Sandlime brick W/C Ratio 0.50 Observations						
Cycles	Start	10	20	3 O	40	50
Length(*0.01mm)	203.4	201.6	208	232	203	206
Weight(g):	11859	11864	11867	11869	11867	11869
R frequency(Hz):	4166	4001	3970	3916	3873	3844
Dyn.Mod.(N/mm')	41164	37965	37388	36413	35577	35050
Reduction in dynamic modulus = 14.8% Increase in length = 0.005% (max 0.057%)						
Sample No.42. 60% Gravel + 40% Sandlime brick W/C Ratio 0.385 Observations						
Cycles	Start	10	20	3 O	40	50
Length(*0.01mm)	231	229	240	254	243	244
Weight (g):	11938	11939	11942	11943	11942	11943
R frequency(Hz):	4104	4041	4027	4008	3997	3984
Dyn.Mod.(N/mm')	402l4	38985	38733	38390	38162	37916
Reduction in dynamic modulus = 5.7% Increase in length = 0.026% (max 0.046%)						

Frost resistance of mixed aggregate concrete depends on the absorption and pore size of brick aggregate. Mixed aggregate concrete with normal construction brick aggregate mixed with gravel started expanding continuously on cyclic freezing and thawing and large expansions resulted in rapid decrease in dynamic modulus whereas concrete with sandlime brick aggregate mixed with gravel showed better frost resistance than gravel concrete for w/c ratio of 0.385.

Keeping in view the characteristics of concrete with waste brick aggregates mixed with normal aggregates, in the ratios of 30:70 respectively, there are no appreciable differences while in the ratios of 40:60 respectively, shrinkage is larger along with lower moduli of elasticity and loss of strength on cyclic freezing and thawing. Such concrete are well suited for low rise construction, pavements and other structures not lying in the areas subjected to freeze thaw in cold regions.

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SUSTAINABLE CONSTRUCTION – USE OF BLENDED CEMENT CONTAINING AGRICULTURAL WASTE IN HIGH STRENGTH SELF COMPACTING CONCRETE

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ABSTRACT

Rice husk is an agricultural waste generated in massive quantitites from rice processing units worldwide. With no worthwhile use, it is a waste material which creates disposal problems. It's high silica content makes it suitable for use with cement. Very limited investigations on rice husk ash have suggested improved strength/durability however its performance in high strength SCC has not been investigated to-date. This experimental study aimed at evaluating the properties of high strength SCC made from blended cements using rice husk ash, Portland cement, natural aggregates and sand. Wide ranging investigations covering most aspects of mechanical behaviour and permeability were carried out for various mixes for compressive strengths of 60N/mm^2, 80N/mm^2 and 100N/mm^2. Compressive strengths of high strength SCC specimen with blended cements for 60N/mm^2, 80N/mm^2 and 100N/mm^2 were observed to be higher by about 4 to 9% than the control specimen, for concrete with 50% Portland cement blended with 50% rice husk ash. Higher elastic moduli and reduced permeabilities were observed along with better sulphate and acid resistance. Better strengths and improved durability of such high strength SCC make it a more acceptable material for major construction projects.

Keywords: Sustainable construction, Rice husk Ash, Self-Compacting Concrete, High Strength Concrete, Agricultural Waste

INTRODUCTION

SCC is a more recent material and was first developed in Japan in 1988 in order to achieve durable concrete structures by improving quality in the construction process. Research and development work into SCC in Europe began in the 1990s and now nearly all the countries in Europe and USA conduct some form of research and development in this material. Self-compacting concrete (SCC) is fresh concrete with superior flowability under maintained stability (i.e. no segregation), allowing self-compaction. The three properties that characterize a concrete as self-compacting are flowing ability - the ability to completely fill all areas and corners of the formwork into which it is placed, passing ability - the ability to pass through congested reinforcement without separation of the constituents or blocking, resistance to segregation - the ability to retain the coarse components of the mix in suspension in order to maintain a homogeneous material. Another advantage is that less skilled labor is required in order for it to be placed, finished and made good after casting. High powder contents are needed in SCC to increase the cohesiveness. Ground granulated blast furnace slag (GGBS), pulverized fuel ash (PFA), or an inert material such as limestone powder are most commonly used according to Goodier, Khayat and Collepardi [1,2,3]. Little research is available in high strength SCC. Similarly, limited investigations on rice husk ash blended with Portland cement and used for normal/high strength concretes have suggested improved strength/durability vide Loo, Kibriya [4 – 8]. However, its performance in high strength SCC has not been investigated to-date. Large quantities of rice husk produced in the rice growing regions pose disposal problems since it has no useful usage. Blending rice husk ash with cements and using it in high strength concretes in major construction projects is likely to reduce the costs thereby aiding cheaper construction with added life due to improved durability. Bulk use of rice husk ashes in blending cements can consume large quantities of this agricultural waste material thereby also solving its disposal problems.

RESEARCH SIGNIFICANCE

The significance of this research is to investigate the possible use of an abundantly available agricultural waste product i.e. rice husk in high strength SCC and to study it's characteristics.

MIX DESIGN

In order to establish a procedure for mix design a linear projection of compressive strength versus w/c ratio from Design of Normal Concrete Mixes method was considered initially beyond the limiting w/c ratio of 0.3 as given by Teychenne [9]. An initial estimate of density was made and later adjusted in the light of values actually obtained. Three high strength concrete mixes for characteristic strengths of 60, 80 and 100N/mm^2 were designed using ordinary Portland cement blended with 50% rice husk ash, crushed natural calcareous limestone aggregates (maximum 20mm diameter) and medium grade sand. Control mix contained 100% Portland cement. Table 1 gives the details of mixes.

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Table 1. Design of High Strength Self Compacting Concrete mixes

Characteristic Strength N/mm^2	W/C Ratio	Cement kg	Sand kg	Water kg	Aggregate kg	Super Plasticizer	VMA %
60	0.36	465	515	168	1302	4 l/m^3	0.04
80	0.32	565	490	180	1214	7 l/m^3	0.044
100	0.28	678	450	190	1124	11 l/m^3	0.05

DESCRIPTION OF TESTS

Three specimen each from three different batches were used in all tests. Specimen used for different tests were as follows: -

Compressive strength/density	150mm cubes, 150mm diameter, 300mm long cylinders.
Flexural strength	150x150x750mm beams.
Stress/strain behavior	150mm diameter, 300mm long cylinders.
Static modulus of elasticity	150mm diameter, 300mm long cylinders.
Dynamic modulus of elasticity	150x150x750mm beams.
Ultrasonic pulse velocity	150mm cubes.
Initial surface absorption	150mm cubes.
Sulphate and Chloride resistance	150mm cubes. (Immersed in 5% H_2SO_4 and 5% HCl solutions for 90 days and measuring weight loss)

All specimen were cured in water at 20^0 C for 42 days before testing.

DISCUSSION OF TEST RESULTS

The properties of the high strength concretes produced are summarized in Tables 2 and 3.

Table 2. Properties of High Strength Self Compacting Concrete

W/C Ratio	Mixes	Cube Strength 7Days N/mm^2	Cube Strength 28Days N/mm^2	Cube Strength 42Days N/mm^2	Cylinder Strength N/mm^2	Flexural Strength N/mm^2
0.36	Control	54	63	66	53.5	6.4
	Blended SCC	56	70	74	58	7.3
0.32	Control	73	82	85	66	7.9
	Blended SCC	74	88	94	74	9
0.28	Control	92	103	106	86	9.8
	Blended SCC	91	108	114	90	11.4

Compressive strength

Compressive strength tests on cubes at 7, 28 and 42 days showed that the rate of development of strength of SCC with blended cement containing 50% rice husk ash + 50% Portland cement was similar to that for control specimen. The compressive strengths of high strength SCC with blended cement containing rice husk ash and Portland cement was somewhat higher than the control specimen. It was observed that compressive strengths kept increasing, as it can be seen from 42-day strengths, as due to low w/c ratios, water is required from external sources for hydration of cement which keeps progressing with time [10]. High strength SCC with blended cement containing rice husk ash and Portland cement was observed to develop 80 to 85% of its 28-day characteristic strength in 7 days. The complete section of high strength SCC specimen including the aggregate and the paste, tends to reach failure simultaneously hence failure of cubes and cylinders tends to be sudden and explosive, typical of high strength concretes as mentioned by Navy [11]. Sudden failure is likely to cause damage or injury unless protective measures are taken. A loading rate of 0.15 to 0.2N/mm^2/s was observed to be safe enough as compared to 0.2 to 0.4N/mm^2 specified by BS1881: Part 116:1983.

Flexural strength

From the values given in Table 3, it can be seen that the flexural strength of high strength SCC with blended cement containing 50% rice husk ash + 50% Portland cement are observed to be higher by 8 to 10% as compared to control specimen. It is also a consequence of higher compressive strength and increased density of concrete with blended cement containing rice husk ash.

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Table 3. Properties of high strength SCC

W/C Ratio	Mixes	ISAT ml/m^2/s	Elastic Modulus N/mm^2	Dynamic Modulus N/mm^2	Pulse Velocity km/s
0.36	Control	0.23	36872	51378.2	4.79
	Blended SCC	0.16	38397	56615.8	5.21
0.32	Control	0.20	37198	54563.1	4.82
	Blended SCC	0.11	39461	59194.7	5.32
0.28	Control	0.17	38218	56684.7	4.84
	Blended SCC	0.10	40623	57954.8	5.40

Stress/strain behavior

Idealized stress/strain relationships in compression are shown in Figure 1. It was observed that the general form of the stress/strain characteristics of high strength SCC with blended cement containing 50% rice husk ash + 50% Portland cement were similar to that for control specimen. All the curves were observed to be virtually linear up to the point of failure, except for the initial small portion, typical of high strength concretes. Higher moduli of elasticity were observed for high strength SCC with blended cements containing rice husk ash and Portland cement as compared to similar concrete with Portland cement only.

Static modulus of elasticity

The average static modulus of elasticity for high strength SCC with blended cement containing 50% rice husk ash + 50% Portland cement was observed to be about 4 to 5% higher than the control specimen. Static modulus of elasticity was observed to be around 38000 to 40000 N/mm^2 for high strength SCC with blended cement containing rice husk ash and Portland cement as compared to 36800 to 38000 N/mm^2 for high strength concrete containing Portland cement only.

Dynamic modulus of elasticity

The average dynamic modulus of elasticity for concrete with blended cement containing 50% rice husk ash + 50% Portland cement was observed to be the higher by about 4% than the control. Table 3 gives the values of dynamic moduli of elasticity of various specimen.

Ultrasonic pulse velocity

The ultrasonic pulse velocities are given in Table 3. Average pulse velocity across high strength SCC with blended cement containing 50% rice husk ash + 50% Portland cement was observed to be 5.3 km/s as compared to an average velocity of 4.82 km/s for control mixes. Hence ultrasonic pulse velocity in the case of high strength SCC with blended cements containing rice husk ash and Portland cement was observed to be 10 to 12% higher than the control mixes. It is due to better quality, higher density and reduced voids in the high strength SCC with blended cements containing mixture of rice husk ash and Portland cement as compared to the control mixes.

Density of hardened concrete

The average saturated and oven-dried densities for high strength SCC with blended cement containing rice husk ash + Portland cement were 2578 and 2449kg/m^3 respectively, as compared to control mixes which were 2480 and 2461kg/m^3, respectively. Hence the saturated and dry densities of high strength SCC with blended cement containing rice husk ash and Portland cement are about 4% higher than the control mixes. It is due to better hydration and packing of finer materials in high strength SCC with blended cement containing rice husk ash and Portland cement. In the presence of higher content of cementitious material and the low w/c ratios, most of the unhydrated cementitious material acts as filler to densify the concrete, whilst the hydration process continues over longer duration.

Initial surface absorption (ISAT)

Results of ISAT are given in Table 3. Initial surface absorption for high strength SCC with blended cement containing 50% rice husk ash + 50% Portland cement was observed to be lower as compared to the control. The values are compared with the guidelines given by the Concrete Society Technical Report # 31 [10].

Sulphate and chloride resistance

For HCL solution, the weight loss for control was 8% as compared to 4% for high strength SCC with blended cement containing 50% replacement of cement with rice husk ash. Similarly, for H_2SO_4 solution, the weight loss for control was 6% as compared to 2% for 50% replacement of cement with rice husk ash. Therefore, the performance of high strength SCC with blended cements was two to three times better in acidic environment and three to four times better in sulphate

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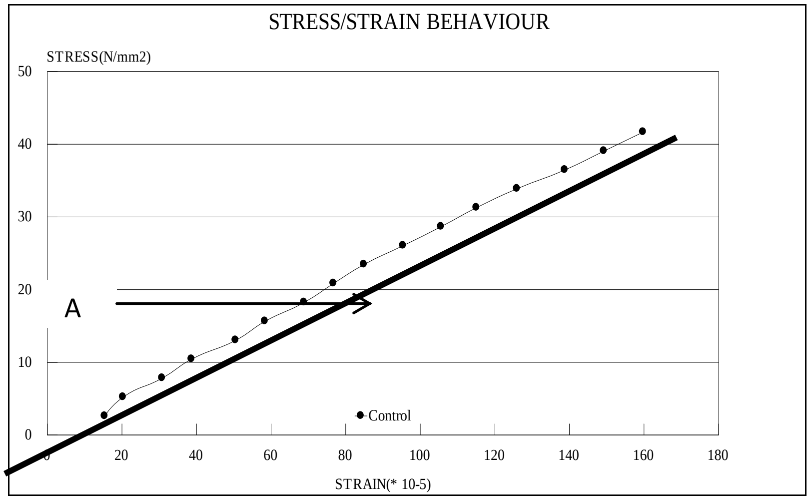
environment as compared to concrete with ordinary Portland cement control mixes. It is mainly due to the negligible amounts of $Ca(OH)_2$ present in the products of hydration of blended cements, lower permeabilities and stable compounds formed due to secondary chemical actions by the silica content of the rice husk ashes.

Shrinkage

Shrinkage of all specimen was observed to be similar for almost all specimen. No appreciable difference in shrinkage of specimen cast from high strength SCC with blended cements and control mixes were observed for 90 days.



Control – 100% Portland cement
A – High Strength SCC with blended cement
Figure 1. Idealized Stress – Strain Curves

CONCLUSIONS

High strength SCC mixes with blended cements containing 50% rice husk ashes can be designed for compressive strengths of $60N/mm^2$, $80N/mm^2$ and $100N/mm^2$ like high strength concrete with ordinary Portland cement. High strength SCC specimen with blended cements developed satisfactory compressive strengths, 8 to 10% higher flexural strength, 2 to 4% higher static moduli of elasticity with values up to $40000N/mm^2$, similarly higher values for dynamic moduli, about 10% higher pulse velocities, 4% higher density, very low permeabilities, similar shrinkage and two to three times improved sulphate and acid resistance as compared to control specimen. Better strengths and improved durability of such high strength SCC is likely to make it a more acceptable material for major construction projects. It will also help in consuming large volumes of agricultural wastes like rice husk ash thereby reducing its disposal problems along with resulting into cheaper cements with stronger and durable characteristics.

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APPLIED SCIENTIFIC RESEARCH AND ITS INFLUENCE ON INNOVATIVE PROCESSES IN ARCHITECTURE AND DESIGN

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ABSTRACT

The article covers applied scientific research and its influence on the innovative processes in architecture and design. The theoretical concepts and practical achievements applied to the satisfaction of material and immaterial needs of modern society which can be reflected in purpose of architecture and design in the XXI century, allowed to identify several strategic directions for their development.

Keywords: sustainable architecture, up-cycling design, digital morphogenesis, environmental architecture/environmental design, generative architecture/generative design.

РЕЗЮМЕ

В статье выявлены прикладные исследования в науке, оказавшие влияние на инновационные процессы в архитектуре и дизайне. Рассмотренные теоретические концепции и прикладные достижения, имеющие отношение к удовлетворению материальных и духовных потребностей современного общества, отражаемых в представлениях о назначении архитектуры и дизайна в XXI веке, позволили определить несколько стратегических направлений их развития.

Ключевые слова: устойчивая архитектура, апсайклинг дизайн, цифровой морфогенез, энвайронментальная архитектура/ энвайронментальный дизайн, генеративная архитектура/генеративный дизайн.

РЕЗЮМЕ

У статті виявлені прикладні дослідження в науці, що вплинули на інноваційні процеси в архітектурі і дизайні. Розглянуті теоретичні концепції та прикладні досягнення, що мають відношення до задовольняння матеріальних і духовних потреб сучасного суспільства, що відображаються в уявленнях про призначення архітектури та дизайну в XXI столітті, дозволили визначити кілька стратегічних напрямків їх розвитку.

Ключові слова: стійка архітектура, апсайклінг дизайн, цифровий морфогенез, енвайронментальна архітектура / енвайронментальний дизайн, генеративна архітектура / генеративний дизайн.

PROBLEM STATEMENT

Investigating the problems and tendencies of modern architecture, V. Babich, A. Kremlev and L. Holodova reveal the possibility of a new global style in the synergistic vision. This style is capable of balanced combination of pluralism and «mosaic» nature of modern art culture, preserving the understanding of architecture as a complex self-organizing system» [1]. Focusing on the effective and expedient unity of philosophy, mathematical foundations and traditional methods of formation, I. Dobritsyna determines the most relevant scientific and practical poles of contemporary architectural and design activity [3]. In the theoretical papers of A. Rappaport a theory of architectural substance is proposed. This theory focuses on a holistic understanding of modern architecture as a relationship between space and time, man and nature, cultural and technical tendencies of reality [5; 6].

The research objective is in revealing applied research in science and its influence on innovative processes in architecture and design. It is also assumes their subsequent analysis for the further specification of integration of architectural and design methods which were outlined in art of postmodernism of the second half of XX century and, most likely, will have the further development in XXI century.

BASIC MATERIAL OF RESEARCH

Applied scientific research, which has influence on the innovative processes in architecture and design, usually based on the main provisions of sustainable development. This concept, among other things, is aimed at preserving the ecological balance of the biosphere. At the same time, the informational richness in terms of production experience, considering usage of technologies and materials, as well as the globality of communication opportunities, consisting in

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the accessibility of multiple information sources, interethnic transfer and borrowing of innovations, contributes to the innovative development of economics, which in turn determines fundamental changes in architecture and design.

The main premises of domestic architectural activity, considering the integration of science, education and production, reflect in projects and theoretical works of Ukrainian specialists. For example, main working methods of architectural workshop of Dmitry Aranchiy, founded in Kiev in 2008, are computing architecture and parametric design, as well as algorithmic/generative design [4].

Along with project developments in the field of architecture, interior design and industrial design, based on usage of digital technologies, the participants of this architectural workshop carry out scientific research (noMad. Architectural system of behavioral assembly, 2013-2015; Monograph «Algorithmic Methods of Architectural Formation», 2016) and implement the results into the system of Ukrainian Higher Education (Tessellation. Implementation of parametric architecture, Kiev National University of Construction and Architecture, KNUCA, 2013).

The group of students of «Information Technologies in Architecture» department (KNUCA, 2015) in theoretical and practical course «Tessellation» under the guidance of D. Aranchy and A. Frolov developed a number of pavilion proposals for Ukrainian EXPO 2015 [4]. During the working process students not only were acquainted with the theoretical base of «parametrics», but also with special software of «Rhinoceros» modeling environment with «Grasshopper» plugin.

Another direction that contributes to the synthesis of advanced scientific achievements and computer technics in the domestic architectural and design activities is holding of competitive events and exhibitions with the appropriate themes. These include the festival of algorithmic/parametric architecture and design «Generation», which took place in the exhibition center of KyivExpoPlaza in 2013 and competition for the best idea in the development of parking building and the adjacent territory of «Lebedskoy» complex. This competition was organized within the framework of «LOFTPARK» project in 2016, prizes in this competition were taken by K. Loreley, A. Rudik, V. Dovgalets and O. Zadybchuk. The annual forum of innovative technologies «InnoTech Ukraine» also should be noted, this forum dedicated to the achievements in such areas as robotics, 3D-printing, smart technologies, education and medicine, takes place in Kiev from 2015.

Among the applied foreign studies, it should be noted the project activity of Canadian architect Philip Beesley [11], who was among the first to create «living» sculptures and compositions «using a 3D-printer, a large number of microprocessors and sensors, stretching and contracting under the influence of electric current» [7]. Algorithms for the development of these projects summarize the scientific achievements of promising computer systems, synthetic biology and mechanics.

In some projects, biological sculptures are installations which give viewers a sense of intimacy and a close connection with nature, immersing themselves in a «space where boundaries between «who am I» and «what am I» obliterated, as well as differences between me, the animal and the stone» [7]. In other projects, these «living» structures are given the role of energy resources that ensure the stable operation of communications necessary for residential buildings within the framework of the «sustainable living» concept (sustainable livelihoods).

American architect and designer, professor of MIT Media Lab, Neri Oxman, in her projects combines «... automated design, additive technologies, materials engineering, synthetic biology for innovative development of interactive systems between microorganisms, our organisms, our consumed products and buildings, in which we live in» [2]. Created, in some cases, «grown» objects, can constantly change and adapt, like representatives of plant and animal world [8].

Transdisciplinary research in the field of architecture and design, based on a holistic understanding of their spatial, temporal and cultural interrelations, as well as disclosing the digital implications of historical past, is devoted to the scientific and practical activities of Mark Burry – architect and professor of the University of Melbourne [10]. In research laboratory of architect Matthias Kohler, taking into account the inalienability of digital technologies in modern design and production processes, criteria are being developed for the formation of a new structural logic system that can be applied in architectural activities [12].

Innovative processes as a result of research and engineering and design development allow more efficient and complex solutions to the problems caused with tendencies of the formation of an environmentally sustainable economic model. In other words, the intention to transform into an environmentally sustainable society and the formation of a dynamically developing economics, in the context of a global relationship between artificial and natural habitat.

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The degree of scientific validity and reasoning of the application of knowledge and skills obtained in various spheres of human life, as well as the ability to act together, combining, integrating and converting scientific and technical potential, all this determines the success of a new model of human relations with representatives of other species and with geochemistry of the planet in complex symbiotic system of a single functioning organism – the biosphere. This is one of the primary needs of world society as a whole.

Taking into account the peculiarities and needs of modern society reflected in notion of designation of architecture and design in the XXI century, several strategic directions for their development have been identified:

– sustainable architecture aimed at use of new, promising, alternative energy sources in order to maintain ecological balance;
– upcycling design, the term «upcycling» is an organic continuation of the notion of «recycling» (secondary raw materials), focused on the secondary and more use of obsolete unnecessary/unused products or products transformed into objects with new consumer qualities with obligatory ecological value;
– digital morphogenesis based on symbiosis of nature laws and achievements of other branches of knowledge, including informational technology, allows creating, in some cases, «growing» objects like biological organisms. This complex approach in shaping, formed on the achievements of biology, geology and geomorphology, subsequently gained wide acceptance in architecture, design and art;
– environmental architecture and environmental design, associated primarily with the expansion of human life sphere, including extreme habitats, suggest use of non-traditional methods and approaches in architectural design, mainly for public spaces;

For example, in the Royal College of Art in the United Kingdom Master's program in the direction of «Environmental Design» was launched in September 2017. The program involves the usage of comparative, multi-scale approaches; methods of anthropological and ethnographic research; systems of computer sounding and visualization, as well as studying future transformations of the environment and ecosystems both on Earth and beyond, taking into account alternative concepts that symbolize other societies [9].

The Master's program of the Faculty of Environmental Design (EVDS, 2017) at the University of Calgary in Canada included course of the Martian architecture «Mars Studio», aimed at design of housing for future colonialists of Mars. At the first stage of the new course, students need to submit architectural projects for a temporary settlement for 6 people (construction in 2030), and at the second stage – to create a residential complex for 100 people (construction 2050) [13].

– generative architecture and generative design, which presuppose a design process with obtaining an infinite number of variations in the shape of both an industrial site and an architectural structure.

First terminological definitions for the concepts «Generative Architecture/Generative Design» appeared back in the 1990s, but at that time it was overall and technically impossible to implement such a scenario. Today this term, as well as the direction designated by it, has received a new development, because the advanced CAD-systems available for the designer can calculate and offer variations of design solutions based on the set requirements. However, these design solutions are the result of purely mathematical calculations and the formation of most of them generated by the CAD-system, as a whole, is not practical for further work. Even today, this generation process has not yet fully unfolded.

Specialists predict that [14], in future these functions will be assigned to the both trained and teaching artificial intelligence (AI) and it is possible to foresee new algorithms of calculation and generation, therefore, a different level of solving design problems in architecture and design. With the real introduction of artificial intelligence, a new stage of transformation can modify the structure of the design process, up to the point that the subject of the process will be not only a person or a group of persons, but also an artificial intellect.

CONCLUSIONS

The considered theoretical concepts and applied achievements allowed to define several strategic directions for the development of architecture and design in the XXI century. These directions obliterate project distinctions between architecture and design. They also establish close connections of architecture and design with other scientific disciplines, their achievements and scientific discoveries.

Innovative developments in this case are a binding «substance» aimed at consolidation and integration of permanently emerging scientific breakthroughs in different areas, which at first sight do not have a common denominator, but later form unified conglomerates. Basis of this thesis consider the fact that architecture and design, which have differences and specifics that determine the nature of their project activities, are summon to solve one fundamental problem: the formation of united body-space environment for human habitation.

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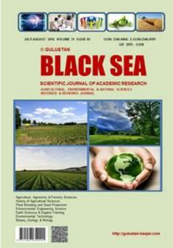

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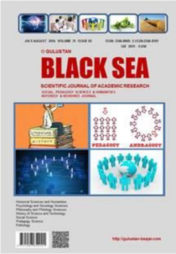

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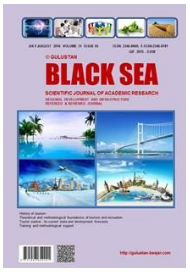

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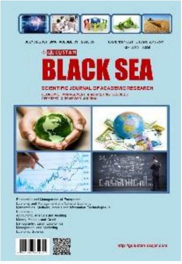

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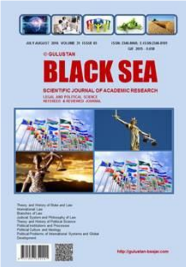

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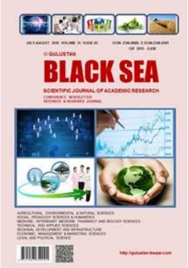

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