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Structural Overdesign of Villa in Oman

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***Abstract*—**Residential projects represent the largest section of the construction industry in Oman. It is widely claimed that designers in Oman tend to unnecessarily overdesign structures, thereby aggravating construction costs. The aim of this research was to investigate the existence and extent of structural overdesign through the investigation of 31 villas which were approved by Muscat Municipality between 2000–2010. The specified villas were structurally redesigned based on the British Code of Practice using the same geometry and material strengths recorded in the drawings. The required reinforcement resulting from the redesign work was compared with the provided reinforcement as per the drawings. The results showed clear cases of extra reinforcement in almost all villas. The difference between required and provided reinforcements in the villas ranged from 2.3–104.8%, with an average of 48.5% and a standard deviation of 24.0. The required and provided weights of reinforcement per square meter of the built-up area ranged from 25.7–71 and 40.9–87.9 kg/m2, respectively. The largest differences between the required and provided reinforcement were in the slabs, followed by the footings.

***Index Terms*—**Oman, Municipality design approval, Structural design, Oman, Villa design

I. Introduction

WITH cost escalation in building construction, owners seek ways of reducing both the cost and time spent on providing decent residential buildings. Designers should be responsible for providing a safe and cost-effective building to suit their clients' needs. However, the objectives of maximizing the degree of technical performance and safety while minimizing cost are usually in conflict. Every design code explicitly stipulates certain safety factors that have been determined to be adequate for loads and material strengths. Overdesigning is a waste of resources as it provides unjustified levels of safety. This paper presents part of already published research work in *Alnuaimi et al. [1]*. A small number of researchers have examined overdesign practices occurring in the Gulf Cooperative Council (GCC) countries. Sadek *et al. [2]* used American Concrete Institute (ACI) [3] provisions for the structural redesign of six typical villas in Kuwait and stated that due to the absence of a unified national building code, large variation in the quality of design practices exercised by private consultants confirms the non-uniformity of designs and structural overdesign of residential units when compared to ACI codes. They found the average percentage of extra reinforcement to be 30% for slabs and 60% for beams and columns.

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Columns were substantially oversized in terms of concrete dimensions as the carrying capacity of these elements as per the existing design was found to be higher than the actual applied loads by as much as 240% on average. The concrete material, steel strength, soil bearing capacity, and structure dimensions were maintained as per the existing design, keeping the reinforcement ratio as the only variable. Arafah *et al. [4]* studied problems related to reinforced concrete buildings due to the absence of a unified national code in Saudi Arabia, starting from the high cost of maintenance to complete structural collapse. They emphasized the need for a unified structural design code in Saudi Arabia to avoid discrepancies in design, maintain quality, and assure safety and serviceability. Al-Negheimish *et al. [5]* studied the design of 41 residential buildings in Riyadh, Saudi Arabia, to evaluate the design practices in the district's small design offices. They concluded that gross and wasteful simplifications were common practice and emphasized the urgent need for a national code of practice for design and quality control. No information was found in the literature about the design practice for villas in Oman; Sadek *et al. [2]* seem to be the only researchers investigating the presence and extent of overdesign in the GCC. Residential projects represent the largest section of the construction industry in Oman; Ministry of Economy [6]. Table 1 shows the annual number of building permits issued during the period 2000-2010 in Muscat; [7], which is home to 40% of Oman's population of approximately 3.6 million. With this statistic in mind, the objectives of this study are to investigate the existence and extent of overdesigned villa structures in Muscat, study the effect of such design on the total weight of reinforcement, determine the causes of overdesign in Muscat's villas, and propose solutions to the issue of overdesign. The significance of this study originates from the fact that it investigates the appropriateness of the design of villa-type housing, which is the most popular kind of accommodation in Oman and the GCC.

Table 1. Building permits issued (2000-2010)

Location / Year	Mutrah	Al-Amerat	Al-Seeb	Baushar	Qurayat	Total
2000	118	96	715	456	90	1475
2001	110	136	835	436	72	1589
2002	131	197	1060	574	88	2050

2003	147	247	1169	565	110	2238
2004	118	247	894	545	115	1899
2005	124	333	924	553	127	2061
2006	142	430	1081	558	129	2340
2007	146	469	1234	574	142	2565
2008	196	812	2251	809	226	4294
2009	215	807	2228	767	198	4215
2010	224	869	2015	663	200	3971
Total (2000-2010)						28697

II. Scope of Work and Methodology

The study data gathered from Muscat Municipality was comprised of drawings of 31 villas approved for construction in various locations around Muscat from 2000–2010. The drawings included architectural, structural, plumbing, electrical, and material information for construction purposes. The villas had been designed by different small to medium-size consultancy offices and lacked signs of the firms have used design software or a named code of practice. Because the British code is widely used for structural design in Oman, the villas were redesigned as part of this research using British code British Standard BS8110:97 [8]. A detailed structural analysis of all the villas was performed to find the bending moments, shear forces, and reactions of the supports using STAAD.Pro structural analysis and design engineering software [9]. The redesign followed BS8110 using Reinforced Concrete Council (RCC) spread sheets [10] for the design of slabs and footings and STAAD.Pro for the design of beams and columns. The materials' characteristic strengths and soil bearing capacity were kept as specified in the approved drawings, and the dimensions of the structural elements, geometry of the building and locations of footings were also maintained according to specifications. The weight of the materials and the dead load were calculated based on the type and thickness of finishes specified in the drawings. Live loads were selected based on the BS6399-Part 1 [11] code requirements for different uses. The concrete density was 24 kN/m^3 and the characteristic yield strength of the longitudinal and transverse reinforcement was 460 MPa. The concrete cover for reinforcement was also kept as directed in the approved drawings. The factors of safety for dead and live loads were 1.4 and 1.6, respectively. The only variable was the amount of reinforcement. Random design checks were carried out for some elements using manual calculations based on the BS8110:97 code to ensure correctness of results. Our use of the term "provided" refers to the amount of reinforcement provided in the drawings approved by the Muscat municipality, while the term "required" represents the amount of reinforcement required, based on the redesign carried out as part of this research. The provided and required amount of reinforcement for all structural elements forming the skeleton were compared. All the reinforced concrete slabs were either one-way or two-way with thicknesses ranging from 120–200 mm. All the beams were reinforced concrete plinth, down-stand, and hidden beams. The width of the plinth beams was 200 mm and their depth ranged from 300–700 mm. The width of the down-stand beams ranged from 200–400 mm with a depth ranging from 320–900 mm. The width of the hidden beams ranged from 300–1400 mm and their depth was from 240–420 mm. Most of the columns used in the selected villas were rectangular. There were also some circular columns, mainly in the open halls. The rectangular dimensions varied from 200–1200 mm and the circular columns' diameters ranged from 200–300 mm. All footings were pad or combined with lengths ranging from 0.9–3.4 m, widths ranging from 0.9–3 m, and thicknesses ranging from 0.3–0.75 m. The length of the combined footings ranged from 1.6–6.4 m, the width ranged from 1.2–3.8 m, and the thickness ranged from 0.3–0.75 m. The RCC spreadsheets were used to calculate the required reinforcement for the footings and slabs, while the STAAD.Pro program was used for the design of the columns and beams.

III. Results

The required reinforcement that resulted from the redesign of the 31 villas was compared with the provided reinforcement given in the approved drawings. The percentage of difference between the provided and required reinforcement was calculated as: (provided – required)/required) x 100). The characteristic concrete strength used ranged between 25–35 N/mm^2, and the soil bearing capacity ranged from 150–250 kN/m^2. The concrete cover to reinforcement of slabs and beams was between 25–30 mm, while for columns it was between 30–40 mm, and 50 mm for the footings. The comparison relates to individual elements and the total required and provided reinforcements for the whole villa. The results (Figures A1- A5) are presented in the Appendix.

A. Slabs

Figure A1 shows the total required and provided reinforcements for each villa and makes clear that almost all the slabs were provided with more reinforcement than required. The total required and provided reinforcement for the slabs of the 31 villas were 159.9 tons and 273.1 tons, respectively. The percentage of difference ranged from -2.8–162.0%, with an average of 75.6% and a standard deviation (SD) of 42.8.

B. Beams

Figure A2 shows the required and provided beam reinforcements. It can easily be seen that all beams have more reinforcement than required. The total required and provided reinforcement for the beams of the 31 villas were 269.8 tons and 387.3 tons, respectively. The percentage of difference ranged from 0–102.91% with an average of 44.2% and a SD of 32.0.

C. Columns

Figure A3 shows the required and provided reinforcements of columns. With the exception of one villa (V26), all the columns were provided with more reinforcement than required. The total required and provided reinforcement for the columns of the 31 villas were 180.5 tons and 246.63 tons, respectively. The percentage of difference ranged from -13.3–78.3%, with an average of 37.4% and a SD of 24.0. There were some cases of under-design.

D. Footings

Figure A4 shows the required and provided reinforcements of footings. Apart from one villa (V30), all the footings were provided with more reinforcement than required. The total required and provided reinforcement for the footings of the 31 villas were 114.6 tons and 169.0 tons, respectively. The percentage of difference ranged from 0–182.4%, with an average of 57.6% and a SD of 45.1.

E. Total Reinforcement

Figure A5 shows the total required and provided reinforcements for all the villas; all were provided with total reinforcement greater than required. The total required and provided reinforcement for the 31 villas were 724.8 tons and 1076.0 tons, respectively. The percentage of difference ranged from 2.3–104.8%, with an average of 48.5% and a SD of 24.0.

IV. Discussion of the Results

Table 2 shows the ratio of the reinforcement-to-unit in the built-up floor area of each villa. Only two villas received less than 10% extra steel. This indicates that the reinforcement was underutilized but the cost and dead load were increased. At the same time, the bond between concrete and reinforcement may have been reduced due to insufficient space between bars. Table 3 shows that the largest percentage of extra reinforcement was used in the slabs followed by the footings, and the lowest percentage was found in the columns. Adding 75.6% extra reinforcement in the slabs aggravated the problem, as slabs naturally receive the large amount of reinforcement. On the other hand, some columns were under-designed, which should be a concern because columns are critical for structural integrity and the possibility of failure should be remote. In fact, overdesign in columns should be considered acceptable for structural reasons [12]. Additionally, columns receive a relatively low amount of reinforcement and concrete, resulting in only a negligible cost increase. It is clear that, in most cases, municipality approval almost guarantees the safety of structures under working load conditions, but the economy of the construction receives insufficient attention. The high SD for the extra reinforcement provided for individual elements indicates obvious variability in the design methods and codes used [Table 3].

V. Concluding Remarks

This study focused on the structural redesign of 31 villas in the Muscat area using the British code. The aim was to find the required reinforcement based on redesign work and to compare the results with the provided reinforcement in the approved drawings. Based on an analysis of the results, the following concluding remarks can be made:

- Most structural elements of almost all studied villas were structurally overdesigned, which was represented by the provided reinforcement being more than required by building codes. The extra reinforcement totaled 162% in the slabs, 103% in the beams, 78.3% in the columns, and 182.4% in the footings.
- The percentage of total extra reinforcement in the 31 villas ranged from 2.30–104.81%, with an average of 48.50% and a standard deviation of 24.00.

Table 2. Ratios of total amount of reinforcement to built-up area

Villa No.	No. of floors	Total built up area (m^2)	Ratio of required reinforcement (kg/m^2)	Ratio of provided reinforcement (kg/m^2)	% Dif.
V 1	2	631.86	41.46	58.84	41.91
V 2	3	911.40	34.08	48.56	42.50
V 3	2	334.56	44.42	64.38	44.95
V 4	2	367.96	44.24	69.36	56.76
V 5	3	623.10	40.70	64.58	58.68
V 6	2	392	41.38	62.60	51.29
V 7	3	1036.8	32.89	45.66	38.83
V 8	2	626.24	39.86	71.12	78.45
V 9	2	350.68	42.03	69.41	65.13
V 10	3	707.40	34.80	62.77	80.34
V 11	3	1122.00	25.69	40.86	59.06
V 12	2	353.72	37.26	65.59	76.02
V 13	3	1078.35	34.74	71.15	104.81
V 14	3	630.00	34.76	52.29	50.41
V 15	3	697.89	33.56	62.39	85.91
V 16	3	810	40.00	67.16	67.90
V 17	3	725.16	35.99	54.77	52.18
V 18	3	597.6	34.77	52.51	51.01
V 19	2	719.94	53.06	75.56	42.41
V 20	2	225	62.49	82.13	31.44
V 21	3	698.72	70.96	87.59	23.44
V 22	2	430.00	44.84	57.72	28.73
V 23	2	447.40	44.48	62.00	39.40
V 24	2	285.84	42.12	74.94	77.91
V 25	2	305.38	43.34	69.37	60.07
V 26	3	846.45	48.18	55.49	15.16
V 27	2	298.33	44.95	58.74	30.69
V 28	2	476.65	47.17	58.75	24.54
V 29	2	300.60	44.61	51.20	14.77
V 30	2	290.17	42.05	44.76	6.46
V 31	3	525.89	45.09	46.12	2.30
Average (kg/m^2)			42.13	61.56	48.50
Min (kg/m^2)			25.69	40.86	2.30
Max. (kg/m^2)			70.96	87.59	104.81
STDV			8.54	10.89	24.00

Table 3. Percentages of extra reinforcement in different members

	Slabs	Beams	Columns	Footings
Average of % dif.	75.63	44.17	37.42	57.61
Standard deviation % dif.	42.84	31.96	24.03	45.06
Max. Value of % dif.	162.04	102.91	78.28	182.35
Min. Value of % dif.	-2.83	0	-13.26	0

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APPENDIX

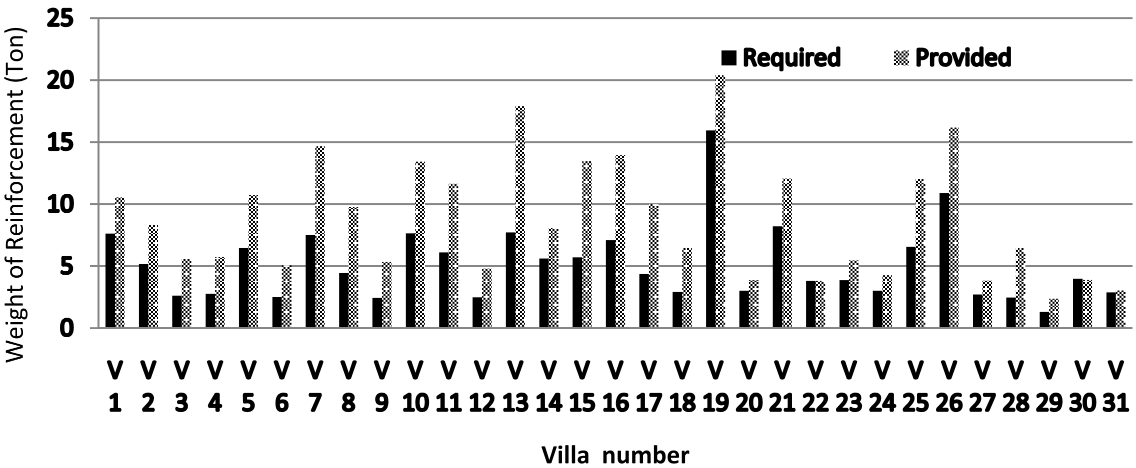

Figure A1. Required and provided slabs′ reinforcements for all villas

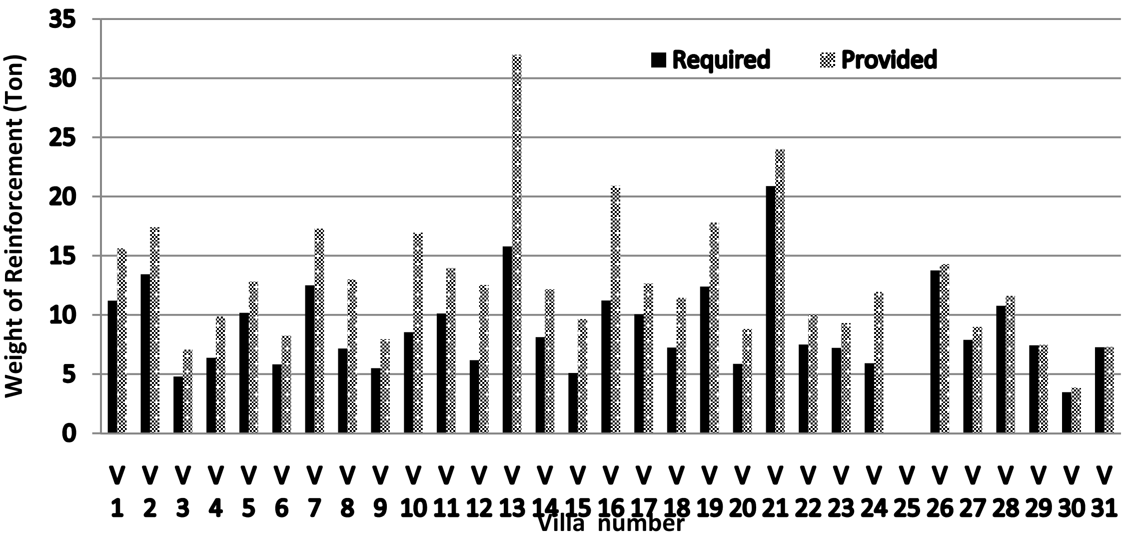

Figure A2. Required and provided Beams′ reinforcements for all villas

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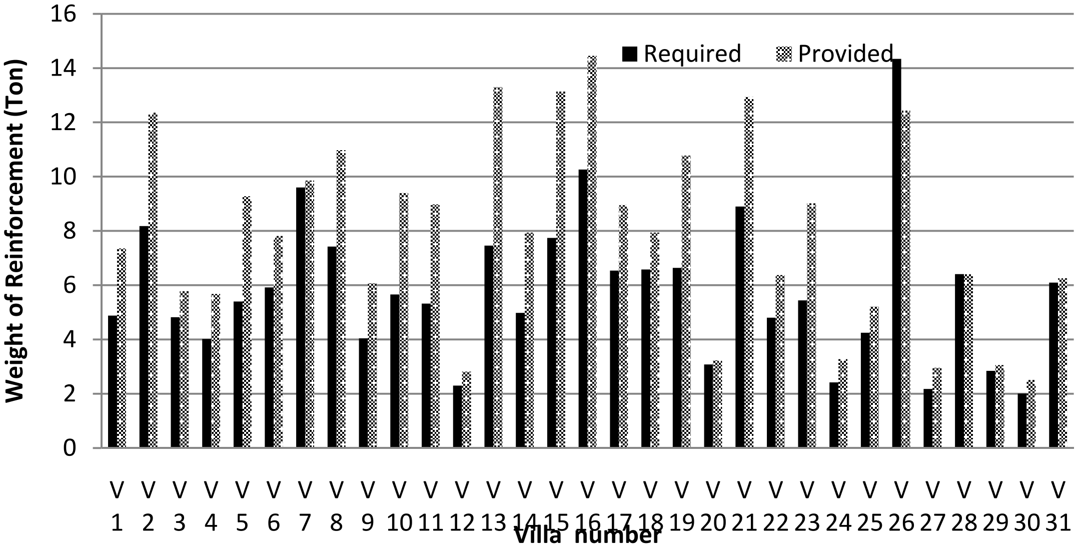

Figure A3. Required and provided Columns' reinforcements for all villas

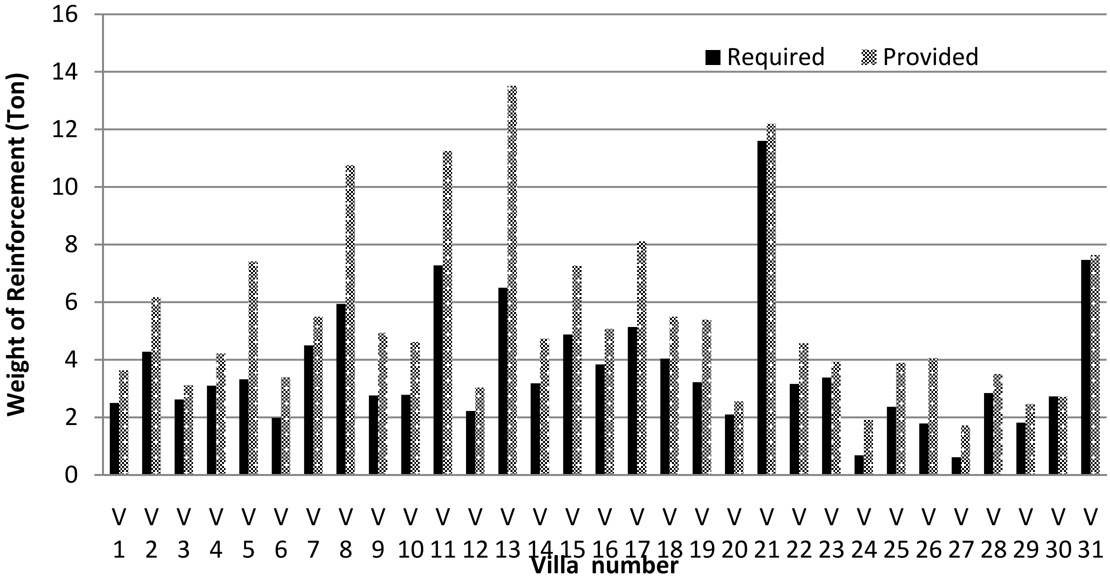

Figure A4. Required and provided footings' reinforcements for all villas

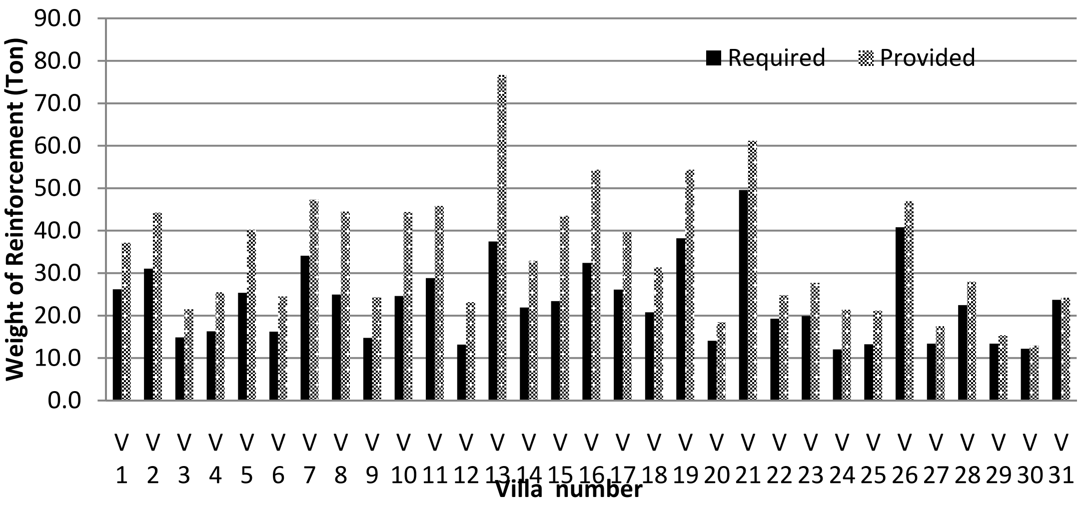

Figure A5. Comparison between total required and total provided reinforcement in all villas

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