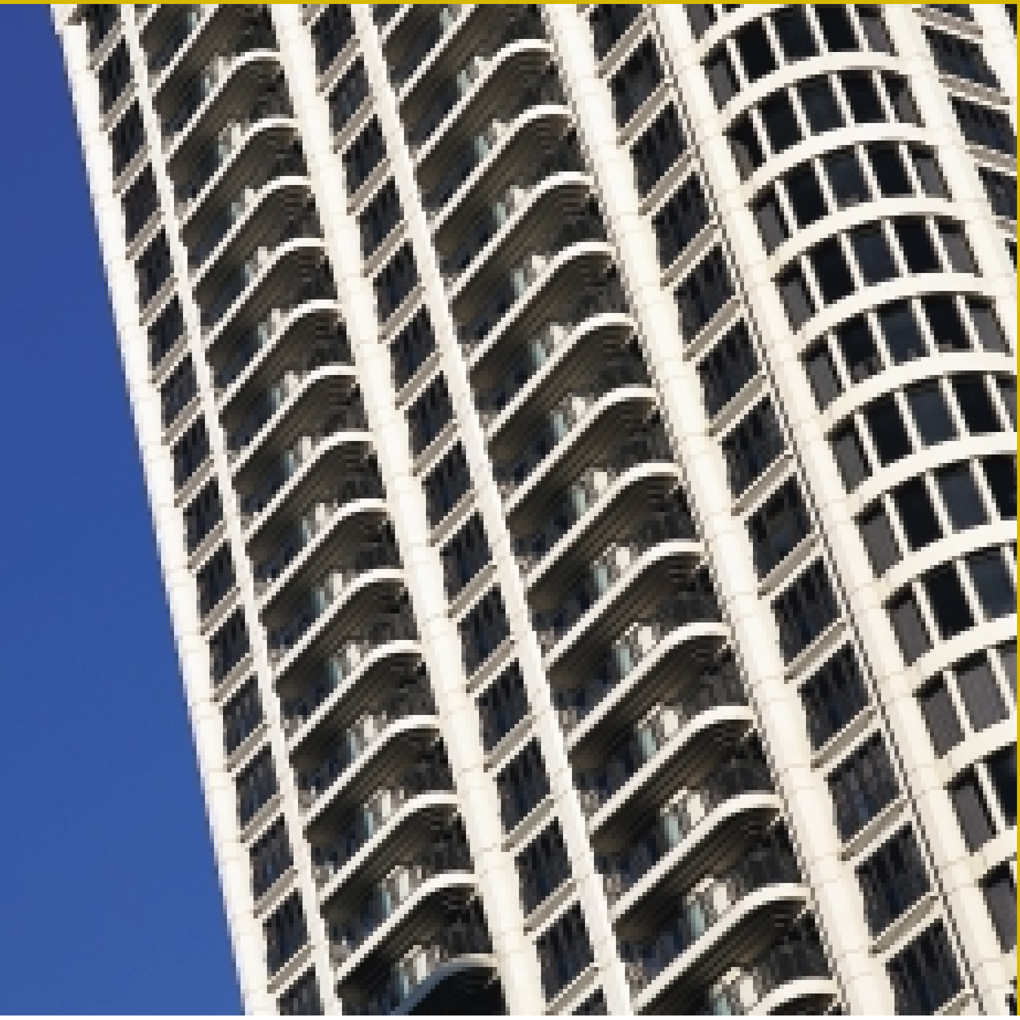
Trends in commercial concrete construction systems



Information is the key to maintaining a competitive edge in today's commercial world: information about how the world is changing, how the marketplace in other countries is evolving, what technological advances are being made. Although market forces elsewhere might be different to those in New Zealand, trends can be observed that have relevance to construction in this country. Those who are first to realise a competitive advantage will profit.

This article explores some of the trends in the concrete construction market overseas. It looks at developments in:

- Precast concrete construction systems
- Self-compacting concrete – a new concrete mix technology
- Extending the limits of conventional construction.

Precast Concrete Construction Systems

New Zealand engineers are very familiar with precast concrete systems, and many of its innovations have been pioneered in this country. However, research currently underway at the University of San Diego, California, is providing a new direction for this very commercial form of construction.

The primary focus in the seismic design of structures is to protect the lives of the inhabitants by ensuring buildings remain standing after an earthquake. This can be achieved by building strong (elastically responding) buildings, or by using ductile design to ensure that a building can dissipate energy in a controlled and predictable way. This energy dissipation typically occurs in appropriately detailed plastic hinge zones. A ductile design philosophy is usually the more economical option, particularly in high seismic zones. However, this is tempered by the fact that a major earthquake will inflict significant damage on such buildings, with the subsequent costs of rebuilding a financial burden for local economies.

Over the past four years, researchers at the University of San Diego in California have been investigating structures that offer the economics of ductile frames but require only minor remedial work after an earthquake. New Zealand engineer Professor Nigel Priestley is leading this research into the seismic performance of precast seismic structural systems, known as PRESSS.

Extensive work has been carried out to determine the behaviour of four different precast structural frame systems and a jointed wall system subjected to earthquake loads. A 60% of full size, five storey precast building, incorporating the different systems, was tested under simulated seismic conditions. The results were extremely satisfactory, with only minimal damage to the model in the wall direction and no significant change in the frame direction – despite being taken to drift levels up to 4.5%, more than 100% highezr than the design drift level.

The structural design of the model building was carried out using the displacement design technique[1]. The

Faster placing
of concrete

Workability tests
of SCC

Better finish around
details and edges
using SSC.

design criterion was that the structure should achieve a maximum lateral drift of 2% under seismic excitation equivalent to UBC zone 4 for an intermediate soil.

The walls and columns included unbonded post-tensioned tendons, which were designed to remain elastic under the imposed lateral drifts and provide a restoring force to the structure (that is, a return to origin upon unloading). At the completion of testing the residual drift was very low – only 0.06% in the wall direction.

The successful performance of the precast frame and wall system is in part attributable to innovative detailing.

A full description of the tests carried out by the PRESSS programme can be found in the literature[1] and more information on the wall system is contained in the next article on page 17. Those attending the NZ Concrete Society Conference at Wairakei in October will have an opportunity to hear more about PRESSS from keynote speaker Dr Priestley.

Self Compacting Concrete

Self compacting concrete (or SCC) is a relatively recent development in concrete technology. Developed in Japan in the late 1980s by Professor H Okamura[2] – it has been predicted[3-4] that by the year 2003, 50% of concrete placed in Japan will be self compacting. It is now generating significant interest worldwide and is starting to be used in projects in the United Kingdom and elsewhere around the world.

SCC is essentially a highly flowable yet stable concrete that is easily spread into place. It fills formwork without any consolidation and without undergoing significant segregation. Segregation resistance combined with high fluidity results in consolidation entirely due to the concrete's own weight.

SCC is produced using readily available standard concrete. The mixture proportions are based on creating a high degree of flowability while maintaining a low water/cementitious material ratio, ($w/c<0.40$). This can be achieved through the use of new high-range water reducing

(HRWR) admixtures, combined with stabilising agents to ensure homogeneity of the mixture. At a dosage rate of 0.5 to 2.0% by weight of cement (460 to 1700 ml/100 kg of cement), specially designed HRWRs can achieve the flowability required for SCC; without HRWRs, a necessary high water content would result in low strength concrete.

The advantages of SCC over conventionally vibrated concrete are:

- faster placement;
- good density, even when reinforcement is very congested;
- increased pour heights, as the limitations of the vibrator's reach are removed;
- quieter construction sites, as vibrators are not required;
- improved finish;
- reduced remedial costs, such as bagging and filling bug holes;
- reduced wear and tear on forms, which can be a significant cost saving for precast concrete construction.

The monetary value of these attributes will, of course, vary from project to project. However, the current cost premium of SCC is likely to reduce as more experience is gained in the use of the material in this country. The enthusiasm of the Japanese for this product would suggest it is an option worth considering.

Although it is being employed in the United Kingdom, as the projects below demonstrate, the use of SCC remains relatively uncommon in Britain as in New Zealand. A number of factors have contributed to this:

- the absence of formal guidelines for specification and use;
- the need for experienced designers and operatives to design SCC mixes and assess key properties, and;
- the absence of established, reliable quantitative tests to assess segregation resistance and passing ability of fresh SCC mixes.

Research into the product is now being carried out, and the UK Concrete Society has established a working party to address these concerns and to develop practical guidelines on the use of SCC. CCANZ is monitoring developments and will keep the New Zealand industry informed of results. Some of the advantages of SCC can best be demonstrated by examining projects in which it has been used.

Millennium Point

The Millennium Point building in Birmingham is a useful example of concrete placement in a space so confined it is unlikely conventionally vibrated concrete could have been used.

Millennium Point is a NZ$350m project, located on five hectares of brownfield land in the Digbeth area of Birmingham. Part of a regeneration programme, it received funding from the Millennium Commission, English Partnerships, the European Development Fund and other organisations. The design of the building aimed to reflect the industrial heritage of Birmingham, which led to the incorporation of 400 exposed steel columns visible throughout the four-storey building.

The structural design required the columns, which are up to nine metres high and internally reinforced with up to eight 40 mm diameter bars, to be concrete filled. The bottoms of the columns were particularly congested by the additional presence of a 1.5 m high inner tube. Typical column erection is shown in Fig 1. Concerns that conventionally placed concrete could not be adequately compacted in these difficult conditions led to the decision to trial the use of SCC and two sample columns were poured using SCC placed via a tremie pipe. The trial was declared a success when the encasement around the columns was removed

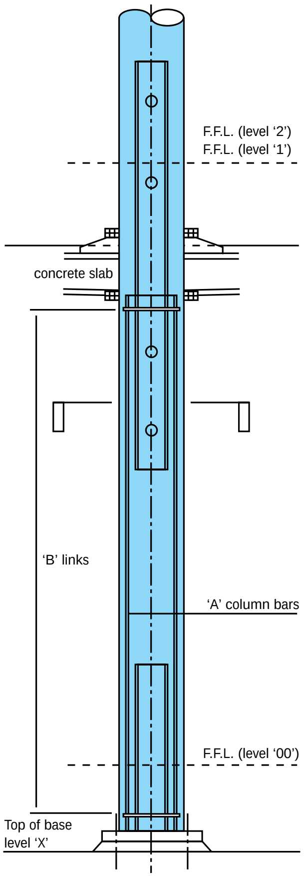


Fig 1:
Typical column elevation

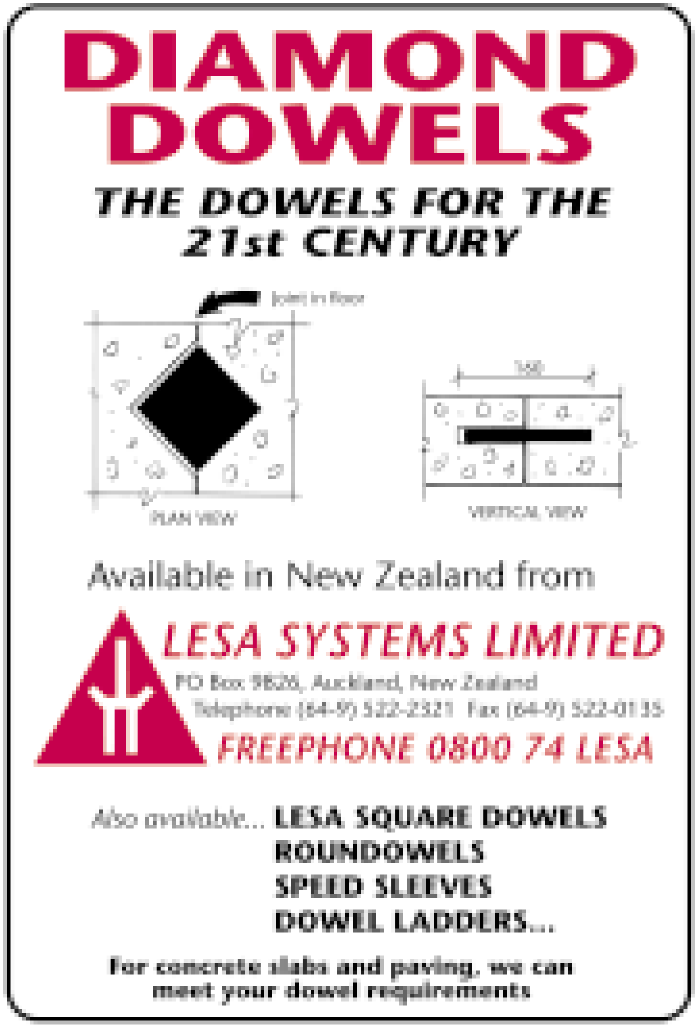


Table 1: The Millennium Point Project Design Mix

Portland cement (73%)	400kg/m^3
Pulverised fuel ash (27%)	150 kg/m^3
5-20 mm aggregate	795 kg/m^3
sand	765kg/m^3
water	190kg/m^3
Superplasticiser by wt of cement	1.5%
Rheology modifier by wt of cement	1.5%
Water/binder ratio	0.35
Specified slump flow	600-650 mm
Specified 28 day cube strength	60 MPa
Typical actual cube strength at:	
7 days	59 MPa
28 days	75 MPa
56 days	81 MPa

Millennium Point, Birmingham

to reveal a very smooth surface free from segregation, with almost no blow holes.

The design mix used in this project is summarised in Table 1.

Feedback from staff involved in the project indicated that SCC was easy to use and reduced placement times significantly.

Milton Keynes Shopping Centre

If Millennium Point demonstrates the use of SCC in a situation where construction using conventionally placed concrete would have been difficult, a shopping centre in Milton Keynes is an example of the selection of SCC when the quality of surface finish was paramount.

The 12 fair-faced concrete columns that support the atrium roof are a significant design feature of the centre. The columns are set out in two rows of six: one 10m high row of elliptical columns tapering from 2050 mm on the major axis to 1030 mm, and another 6m high row of tapering conical columns of 1300 mm to 900 mm diameter.

The columns' complex shape, congestion of reinforcement, and the need for a superior surface finish represented a considerable challenge to the contractor. To achieve the desired finish, the tall columns needed to be poured in one lift. SCC was proposed and two large-scale site trials were conducted, with a successful result: the finish quality was achieved and the concrete cores demonstrated excellent aggregate distribution.

Visual examinations of the 12 completed columns revealed dense, compacted homogeneous concrete, although minor blemishes (associated with the impermeable shutter and taper design) were observed. However, given the extreme construction constraints and requirements, the result was considered better than a conventional concrete finish.

Extending the Limits

The Jin Mao building in Shanghai is an example of conventional technology being pushed to new boundaries. Completed in August 1997, Jin Mao, at 420.5 m high, is the third tallest building in the world[5]. It has a three-storey basement and 88 storeys above grade.

The project presented two significant challenges: how to manage the massive foundations, 64 x 64 m by 4 m thick, and how to economically deliver concrete to the top of the building.

Mass concrete pours such as the foundation mat of this building require careful consideration of the heat generated during hydration and the logistics of physically handling large volumes of concrete. The designers originally specified that the mat be split into eight blocks to limit thermal gradients during hydration.

Table 2: Concrete Mix Proportions

No.	Concrete strength MPa	Concrete mixture proportions by weight						Max. pumping height meter
		Cement	Water	Sand	Aggregate	Fly ash	Admixture %	
1	60	1.000	0.353	1.142	1.879	0.075	2.36	174
2	50	1.000	0.483	1.862	2.033	0.167	3.50	265
3	40	1.000	0.495	1.878	2.024	0.195	3.20	383

Table 3: Approximate quantities per cubic metre of concrete

	60 MPa Concrete		50 MPa Concrete		40 MPa Concrete	
	% by Wt.	Kg	% by Wt.	Kg	% by Wt.	Kg
Cement	22.4	520	17.9	416	17.8	413
Water	7.9	183	8.7	202	8.8	204
Sand	25.5	592	33.4	776	33.4	776
Aggregate	42.0	975	36.4	845	36.0	836
Fly ash	1.7	40	3.0	69	3.5	81
Admixture	0.5	12	0.6	14	0.5	12
Total	100.0	2322	100.0	2322	100.0	2322

Jin Mao, Shanghai

However, the designers and contractor worked together to develop a concept that would allow the mat to be poured in one continuous operation. Confidence that the thermal gradient could be maintained within acceptable limits was achieved by:

- testing available cements to determine which provided the required strength with lowest heat of hydration;
- the approval to base strength targets on 56 day rather than 28 day tests;
- the use of 16.7% fly ash;
- the installation of cooling pipes in the concrete;
- the installation of 127 computerised temperature sensors (these provided a continuous readout of the concrete's internal temperature, allowing cooling rates through the pipes to be modified if required).

The pour involved the continuous placement of 13,500 m^3 of concrete, in 46.5 hours. Four batching plants were used with another on standby. The concrete was delivered on site using 100 mixer trucks, each with a 6 m^3 capacity. The pour was successfully completed with temperatures remaining within the design limits.

A 375 kw pump provided an economical answer to concrete delivery 'on high'. Pumped concrete was used up to a height of 382.5 m, a new record surpassing the previous maximum height of 370 m.

Today, China, Japan, the UK; tomorrow? New products, processes and systems have the potential to provide the industry with real competitive advantages. While these new trends in concrete construction are currently found overseas, the message for those working in the industry is clear: keep abreast of developments, as New Zealand won't be far behind. Those who search out the opportunities and grasp them with enthusiasm will reap the rewards.

References

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