Chartered Membership Examinations, April 2006

The examiners' reports are to be read with reference to the April 2006 question paper available from the Institution at £3 for members and £4 for non-members

The April 2006 Chartered Membership examination continued to follow the format introduced in 2004. This year's examination was attempted by a total of 755 candidates, 20 less than last year, of which 347 took the examination in the UK. The UK pass-rate was 38.3% and the overall Non-UK pass-rate was 32.3%. The Hong Kong candidates' pass-rate was 30.1% and other Non-UK centres' pass-rate was 36.6%. The overall pass-rate for 2006 was 35.1%, a slight improvement on last year.
The examiners draw future candidates' attention to themes which reoccur each year:

- Candidates should identify the crucial problems posed by their chosen question which must be solved for a successful outcome. They should communicate their understanding of these problems clearly, then address the problems in their proposed solution and not ignore them. They should produce calculations for the key elements and not spend too long on less important items.
- Candidates should avoid neglecting part 2(e) until near the end of the examination, when their work suffers from severe pressure of time. It is preferable to highlight matters of key importance in part 2(e) rather than prepare a list of activities, some of which are trivial.
- Candidates can lose marks by using pre-prepared or 'standard' answers if they are not relevant to the question. At best, such answers may help as a check-list of items to be considered. At worst they give the impression that a candidate has not understood the implications of the question and has not realised why the 'standard' answer is inappropriate.
- Presentation is important. If examiners cannot read what candidates have written or make sense of their diagrams, marks will be awarded more reluctantly than if the candidate's ideas were clearly and concisely expressed.

QUESTION 1 PORT CONTROL TOWER

The question called for the design of a tall port control tower in the centre of a busy seaport complex, founded on an existing quayside with a 10m thick layer of soft clay overlying competent rock. Candidates needed to solve the problems of stabilising a tall thin shaft and overcoming onerous construction requirements. The shaft was to be constrained within a 6m square footprint, with a minimum core dimension of 4m. This allowed flexibility in the shaft options, including the optimum solution of a circular shaft. Other options included a steel lattice tower or frame, or a plated steel box, and pre-cast concrete options were also possible. The construction constraints of the site should have precluded the use of extensive *in situ* concrete casting, although a few candidates identified that concrete could be batched off-site and shipped in by barge.

In designing the shaft, candidates who provided annotated sketches to demonstrate their proposals gained marks. Some of the braced steel frame options failed to recognise the need to prevent lozenging: moment-resisting bracing would be required for this form of structure as cross bracing would seriously impede the function of the shaft. Few candidates attempted a steel plate/shell design, although those that did generally showed a good understanding of the local stability requirement. A few candidates failed to appreciate the requirements for the intervening 1m structural zone and filled it entirely with concrete resulting in massively conservative designs. The tall and slender tower was very sensitive to deflections but only a few candidates recognised the need to calculate the lateral movement under wind load (static or otherwise). Some candidates extended the shaft into the control room which was at odds with the desire to minimise obstructions to viewing the port.

The foundations were reasonably well designed. The soft clay band at the surface meant that the lateral and vertical forces needed to be transferred down to the rock-head 10m below using piles. Schemes such as rafts were not feasible as they would not be able to accommodate the overturning forces generated by the tower. Some candidates failed to appreciate the need to continue to resist lateral forces down to the rock level and produced piles without sufficient bending resistance.

The design was constrained by limits on construction activities and headroom. These were not dealt with well (if at all in some cases). It is imperative that designers understand how their structures can be built and how the unique characteristics of a site will affect the design. Few candidates gave thought to how they would lift the control room structure into place.

Candidates were required to write a letter to explain how to reduce excessive vibration in the equipment room. The source or form of vibration was not identified, thus it was for them to consider forms of vibration present (wind response, reciprocating/rotary machines, etc.) and propose solutions. Most recognised the need to damp out the vibrations or to provide some form of base isolation.

Calculations tended to focus too much on minor elements in the control room with limited effort expended on the design of the shaft and the foundations, the two key elements to the stability and economy of the structure. Candidates are expected to identify and provide calculations for the major structural elements; to spend time on trivial items is to waste it. Drawings for the structure should have been straightforward because of the relative simplicity of a prismatic shaft. Some failed to include important cross-sections of the shaft, while many failed to observe the requirement to identify and draw the critical details. For this structure, these would be the interfaces of the shaft with the control room and the foundation.The construction method statements were generally poorly done. The need to lift building materials to significant heights was not considered by some, nor was the requirement to work within a busy port. Candidates should have recognised that delivery of pre-fabricated material to site was important in reducing site traffic, along with the need to work within the site boundaries. Lateral thinking, such as using the port to transport material, was well received.

QUESTION 2 AIRCRAFT HANGAR

A new aircraft hanger was to be designed to accommodate two aircraft and a three-storey administration centre, and constructed within a 90.0m by 50.0m site boundary, with limited height. Clear plan areas, heights and access doors were state for each aircraft. Areas and glazing requirements were specified for the administration centre. The hangar was to be clad with insulated metal cladding panels and the roof with metal decking. Ground conditions were straightforward but varied across the site.

The brief deliberately gave candidates freedom to consider various plan layouts and enabling the design of the structure to be optimised. No limits on column position/spacing were given as it was anticipated that candidates would recognise that the requirement for a clear plan area for each aircraft would dictate the design.

The identification of shallow rock beneath one end of the site, together with the dominant openings formed by the hanger doors, was expected to highlight the need for consideration of wind reversal and uplift when designing both the roof structure and the foundations. Few candidates appeared to appreciate the effect of varying ground conditions on the design, perhaps because of the mention of rock. Thus many put forward inappropriate foundation solutions: some opted for shallow pads without any regard for differential settlements between foundations resting in the different strata, others proposed rafts or trench-fill even where rock was virtually exposed at the surface.

Most candidates proposed satisfactory layouts but some, having found one layout that worked, proposed a simple structural variation as their second solution, e.g, using portal rafters instead of trusses on the same plan. In some cases there was no explanation or indication from the sketches in Part 1(a) as to how the overall stability of the structure was to be achieved and candidates lost marks for this omission.

The letter in Part 1(b) involved the need to increase the clear height below the roof when the steelwork had already been fabricated. Possible solutions included lowering the ground floor slab, expensive because of the rock, modifying the steelwork, or the provision of upstand 'stubs' from the foundations to raise the steelwork above. It was also anticipated that candidates might discuss the possible impact on the overall height of the building and whether the 15.0m maximum height limit could be increased. Many candidates failed to understand the question, and suggested a redesign even though the steelwork had already been made.

In part 2(c), candidates often looked at the easier, minor, parts of the structure but did not design the more complex elements. Few properly addressed wind uplift with the hanger doors open, although some provided wind girders to resist lateral forces when the doors were shut. Many failed to consider deflection of the roof structure adequately, under normal loading or during wind reversal, and the roof trusses were under-designed in several instances. Drawings generally lacked detail, included basic dimensions, and often failed to meet the required suitability for estimating. They often failed to include details of critical connections.

The method statements were of variable quality, many little more than a list of activities ignoring aspects of safe construction or temporary works to erect the structure. Very few would have been acceptable in practice, of concern given the increasing emphasis on the designer's role in health and safely.

QUESTION 3. FOOTPATH OVER AN EXISTING CANAL

A structure was required to carry a footpath over a canal adjacent to an existing arch. Presentations were variable: some were very good but in some the handwriting was difficult to read, drawings poor and lacked detail. A large number of candidates failed to complete the paper and the method statement was often omitted.

The most elegant solution was to provide a lightweight footbridge independent of the existing bridge, supported on lightweight foundations. Options presented included single span trusses, timber and steel beam structures. Three-span arrangements were also possible and were easier to adapt for the rise in level.

Where a truss was chosen stability of the top flange was a critical element and the candidate had to show understanding that the top member must be restrained or designed for compression, or U-frame action used.

Alternative options included widening the arch with similar construction or a reinforced concrete arch. This is an expensive solution with complex considerations such as the joint with the existing structure and foundation stability during and after construction. A number of candidates chose to provide an additional traffic lane with the footpath but, since the client's requirement was only for a footpath, this was considered to be grossly uneconomic. Highway bridge-type construction to support the footpath and piled foundations was also considered unnecessary and uneconomic, as was a new deck on the existing abutments or a replacement structure.

Some candidates considered supporting a new structure cantilevered from the side of the existing bridge. This was a complex option because it required adequate anchorage to support the cantilever elements in the existing masonry, but candidates who chose it, and who demonstrated understanding of how an arch works and knowledge of assessment and testing gained high marks.

Some candidates chose to carry out detailed calculations in part 1(a) for both their options, but did not adequately describe the functional framing and load transfer. In part 1(b) the scope depended on the chosen solution, but candidates were expected to discuss the slope of the ramps and access. Those who had chosen an arch that matched the shape of the bridge had little to say here.

The calculations and drawings were generally well-presented but some candidates did not design all the key elements or omitted important details. They often failed to consider the stability of the existing foundations or the canal when constructing large foundations nearby. The locations of bearings were sometimes not in the best position for load transfer into the deck construction. A few encroached on the clearances required to the footpath or canal in one of their options. Falsework for an *in situ* concrete deck would also temporarily obstruct the headroom clearance and candidates did not explain how the impact on canal users would be mitigated. In part 2(e) many presented only a sequential list of construction operations with little or no mention of temporary works, environmental or Health & Safety issues omitting e.g. working over water, excavating on a slope, possible pollution to the waterway with debris and construction material, safe working with a masonry arch structure particularly if demolition is involved, etc.

QUESTION 4. HIGHWAY VIADUCT THROUGH AN EXISTING CAR PARK

The question called for the design of a viaduct carrying a new 2-lane highway through an existing multi-storey car park, which was to remain open throughout the construction period. A clearance envelope for the new highway throughout the length of the car park was specified.

Successful candidates proposed a satisfactory supporting system for the existing principal structural members.

Creating the clearance envelope for the new viaduct required the existing columns along its route to be removed or relocated. This required temporary and permanent supports to the existing columns above the new viaduct, which could be achieved by erecting transfer elements on the floor above. The existing columns under the line of the viaduct could remain. To cater for the increased load from the viaduct, the existing columns on gridline D would need strengthening, and the strengthening would be required down to the new foundation. The site environment created limited working space which affected the type of foundation chosen for the new supports along gridline K.

Good candidates answered every section of the question and presented the answers clearly. They offered two schemes which were sufficiently distinct in structural concept rather than just variations on the theme, and illustrated the proposals with sketches and load-path descriptions showing that they clearly understood the structural behaviour of the scheme. Some candidates found this difficult and appeared to have made their choice from the outset, not developing their second scheme sufficiently. Others proposed schemes which lacked initiative and ingenuity, and some gave scheme descriptions which were generic and not specific to the question.

In part 1(b), candidates were expected to identify the durability of the concrete as a problem and propose solutions.

In part 2, good candidates identified and undertook sufficient calculations for the critical elements of the structure, such as checking transfer members for punching shear. The quality of drawings was variable with most poorly presented, not providing sufficient information for cost estimation and not clearly conveying the necessary design information.

The majority of candidates did not complete the method statement, and it rarely addressed the issue of 'safe construction' and structural stability of the temporary works and the existing building.

QUESTION 5: HOTEL BUILDING ON AN EXISTING QUARRY

The question required candidates to design a three-storey hotel partly constructed over a backfilled quarry. The hotel was split into three zones with a basement in zone 1, a two-storey height entrance area in zone 2 and a car park at ground floor level in zone 3. Restrictions were placed on column spacings. Part 1b of the question required candidates to write to the client to describe the implications of the introduction of a swimming pool into the building.

The question provided scope for a large number of solutions with various grids, materials and construction techniques all possible. The main issues to be addressed were the change in founding strata and implications for differential settlement (particularly during construction), the construction and waterproofing of the basement, the presence of a high groundwater level which meant that flotation needed to be considered, the car park in zone 3 which introduced a need for a transfer structure above in order to produce a workable layout, and the two-storey height columns and curved beams in zone 2. Candidates were also expected to include appropriate movement joints and to note the double-storey-height area in zone 2 and design the columns accordingly. Where offering two distinct solutions, simply changing from a beam-and-slab solution to a flat-slab solution was not sufficiently distinct.

Candidates attempted to answer part 1(a) using many words, but clear properly-annotated sketches, roughly to scale and with a few relevant accompanying notes, are a far more effective method of communication. Calculations provided for part 1(a) should be 'rule of thumb', for example using span-to-depth ratios for preliminary member sizes. More complex calculations are better saved for part 2c. Candidates who attempted detailed calculations at this stage invariably ran out of time in the later parts of the question.

In part 1(b) letters should address the key issues clearly and concisely. It should be assumed that the client, although likely to have a reasonable understanding of general engineering issues, is not a structural engineer and the points should be made in layman's terms. Long-winded descriptions of a complex technical nature were best avoided. Letters were frequently too long, contained irrelevant information or were simply unintelligible.

In part 2(c) candidates often failed to design the critical elements and spent too long producing repetitive calculations for simple beams or slabs of various spans. Drawings were often far from adequate for a costing exercise and candidates appeared not to understand what information they needed to provide and what details may have been expected.

Method statements and programmes in 2(e) frequently appeared to be generic lists of activities rather than relating specifically to the project in question.

CM Examination 2006

Qu.	Pass	Fail	Total	(%Pass)
1	18	15	33	54.5
2	54	83	137	39.4
3	17	35	52	32.7
4	1	4	5	20
5	95	242	337	28.2
6	77	108	185	41.6
7	1	2	3	33.3
8	2	1	3	66.6
CM	265	490	755	35.1

QUESTIONS 6. RAILWAY STATION BUILDING

A two-storey building was required, with constraints on the location of supports for the upper floor and roof. There were numerous options for the structural form in any of the common construction materials (concrete, steel and masonry). Many candidates used transverse frames, in concrete, steel or combinations (concrete frame and floors or steel frame with concrete floors) with single or multiple spans supporting precast or *in situ* concrete slabs. A single transverse span of 14m would have required large foundations at the north and south elevations, which would be difficult to justify given the proximity of an operational railway. Longitudinal frames could also have been used over the central portion with transverse frames appropriate to the open spaces at the north and south elevations. Solid partitions could have been used for mechanical robustness and safety in a public building. The roof member could have been a truss spanning between columns or could have formed part of the top member of a portal frame. Overall stability could be provided in the longitudinal and transverse directions by vertical bracing located within partitions and tied into the roof plan bracing; alternatively portal frames could be used.

Foundation proposals were mostly for piles of various sizes. Stone columns or ground improvement down to 6m below ground level was also possible. A concrete raft was suggested by a number of candidates without ensuring that the imposed ground pressure was within the capacity of the soil below. Large-diameter piles would be uneconomic and it would be difficult to fit the piling plant on site. Some candidates proposed individual pad footings at depth, which is uneconomical and inappropriate. Many candidates realised the complications associated with building near a railway line, but few properly addressed the constraints. Some correctly identified vibrations transmitted to the building from the railway as a problem.

In part 1(b) successful candidates gave a coherent and reasoned explanation as to how the project could be modified to accommodate the unexpected underground services alongside the proposed building. Possible solutions involved bridging or cantilevering over them. Bridging would require foundations in the railway platform, which could be difficult to provide. Cantilevering would require transverse ground beams to cantilever for 3.3m with column loads at the northern ends, for which an overturning check would be required. Many suggested relocating the services, which highlights a lack of appreciation of the time, disruption and cost involved in doing so in a rail environment.

In part 2, good candidates provided calculations with sufficient, not too much, detail. They appeared well versed in using section tables in arriving at member sizes. Stability was not adequately covered by many candidates. Drawings were generally very poor. Successful candidates carried through their selected scheme into the design calculations and drawings. Many produced details which were neither critical nor appropriate: they should have included stability, main beam-to-column connections, foundations and roof connections. Method statements were often generic and did not convey the critical structural aspects for the safe erection of the chosen scheme. Some programmes were unrealistic indicating a lack of adequate construction experience.

QUESTION 8*. SCHOOL BUILDING IN AREA OF HIGH SEISMICITY

Candidates were required to design a two-storey L-shaped block housing classrooms, halls and offices. The new block was an extension to an existing school, and disruption to school activities had to be minimised during construction. The stiff clay ground conditions were favourable. A seismic response spectrum was given for a 475-year return period, which had a peak ground acceleration on rock of $4m/s^2$ and a rapid reduction in spectral response for periods exceeding 0.25secs, suggesting that lengthening the period of the building would result in a greater than usual reduction in response.

The nature of the structure and its supporting soils were fairly straightforward, but two features necessitated special consideration in the context of seismic design. Firstly, the office area at the top of the building was set back in plan from the two floors below, creating an irregularity in elevation, and a potential problem with support to the roof at the setback face. Secondly, the L shape created a plan irregularity, exacerbated by the presence of the additional office floor on one arm of the L.

Braced and unbraced solutions for lateral resistance were proposed in both concrete and steel, with a braced solution recommended as optimal. Most candidates realised that a steel frame might be easier to construct on this restricted site, and by reducing the mass also reduced seismic forces. Concrete was, however, also a valid option for this low-rise building on good foundation soils. No-one recognised the potential advantage of lengthening the response period using an unbraced (or even seismically isolated) solution, given the unusual shape of the design response spectrum. Some noted that a good distribution of bracing elements would help control the torsional response associated with the plan irregularity, but none suggested a separation joint might be considered between the assembly/dining arm of the L and classroom arm. The stairwells were selected as a convenient place to locate some of the bracing elements.

The gravity framing required the absence of columns in the circulation areas and a minimisation of columns in the assembly and dining halls. To avoid internal columns in the latter, a 10.5m beam span was required, which most candidates appreciated was easily achievable. Supporting the roof to the second-floor office area required columns supported on transfer beams at second floor level (the majority solution), or columns extending down into the classroom below (inappropriately chosen by a minority), or beams extending over the terrace to the outer line of columns (not suggested). The former would have been difficult to make satisfactory for seismic resistance if the transfer beams had also been acting as moment frames resisting lateral forces; in fact, braced solutions were adopted, so this was acceptable. Shallow pad foundations were proposed but few mentioned the need to check for seismic uplifts at the bracing positions.

In part 1(b) candidates were to recommend upgrading measures for the block to be used as a disaster shelter which would survive the 475-year earthquake. The introduction of seismic isolation was suggested as a possibility, although the practical details of the level of the isolation plane were not discussed, and most candidates realised that equipment would need to be secured and non-structural elements checked for adequate performance under the imposed seismic drifts.

The method statements for construction generally appreciated the safety and programme implications of a restricted site within an existing school, but tended to lack detail of construction methods.

QUESTION 7. SUBSEA EQUIPMENT PACKAGE

Candidates were required to design a small subsea package to be installed on an existing subsea structure, an engineering task common in the offshore industry where existing facilities are routinely upgraded for alternative uses.

The question was a straight-forward structural engineering test, even for candidates without subsea experience. The structural framework solutions for this question were relatively simple and the challenges were in overcoming the constraints set out in the question. It is clear from the submissions, that candidates did not take sufficient time to read and fully absorb the question requirements. One main problem was the determination of installation loads from the hydrodynamic forces generated by the package moving in the water column; this was a significant design case, not considered adequately by any of the candidates.

While most candidates indicated load path diagrams for the truss structure, no attempt was made to show bending moment diagrams for options where bracing was omitted. This would have provided an indication that the candidate understood how stability is achieved for a non-braced structure.

Candidates did not show a clear understanding of which load cases from the temporary and permanent conditions governed the various parts of the structure. A few simple high-level checks would have established the governing load cases for components, in order to provide a basis to perform more detailed checks. However, the load derivation and code checks that were presented appeared haphazard and disorganised.

The letter was well written by most candidates.

In part 2, candidates did not allocate sufficient time to the general arrangement and detail sketches section of the question. The influences of subsea installation constraints were not adequately considered. This is an important part of the submission, where capability may be demonstrated with good detail sketches, simply and quickly.

The final installation study 2(e) was also poorly answered, with fundamental requirements being ignored e.g.

- no mention of installation bumpers and guides, necessary for installing the equipment package subsea;
- no discussion on tie-down operation; whether diver, ROV assist or remote mechanical/hydraulic solution;
- no monitoring of installation sea states.

This is a simple part of the question and candidates, when they plan their time effectively, can pick up high marks here.

** Candidates should note that question 8 for the April 2007 CM examination will be based on earthquake engineering and not structural dynamics.*