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(A DIVISION OF REMEDIAL BUILDING SERVICES AUSTRALIA)

INTEGRATED SOLUTIONS FOR THE BUILT ENVIRONMENT

FIRE PERFORMANCE SOLUTIONS

THE RESTORATION OF A HERITAGE SLAB

12th July, 2018

OVERVIEW

This white paper describes a case study of a real-world project proposal for a heritage building upgrade, how the technical challenges and lack of key information guided the decision-making process, fire engineering design, testing and solutions.

PART 1
In “Heritage Fire Performance Upgrades – What’s Involved?” we discuss the growing trend in the remediation industry and the importance of maintenance work and passive fire protection upgrades to Australia’s oldest buildings.

PART 2
In “The Intricacies of a Coffer Slab” we discuss the differences, details and condition of the coffer – waffle slab compared to a typical modern slab.

Part 3
In “Consider the Modern NCC” we explore the evolution of legislation and the building code from the early 1930s to the introduction of “Performance Based Solutions” in recent times.

Part 4
In “Ad Hoc Tests” we discuss the initial slab assessment and how it contributed to the engineering design methodology and analysis.

Part 5
In “The Proposal” we discuss the solutions recommended in collaboration with FERM Engineering, Tremco-Illbruck and Exova-Warringtonfire.

Part 6
In “Ex Scientia Vera” we briefly discuss the options utilizing Nullifire products and how they help builders and engineers achieve the required fire performance.

PART 1 - HERITAGE FIRE PERFORMANCE UPGRADES

Fire protection is the process of using fire resisting materials, detectors and active systems such as sprinklers designed to save lives and increase the structural longevity of a building during a fire event.

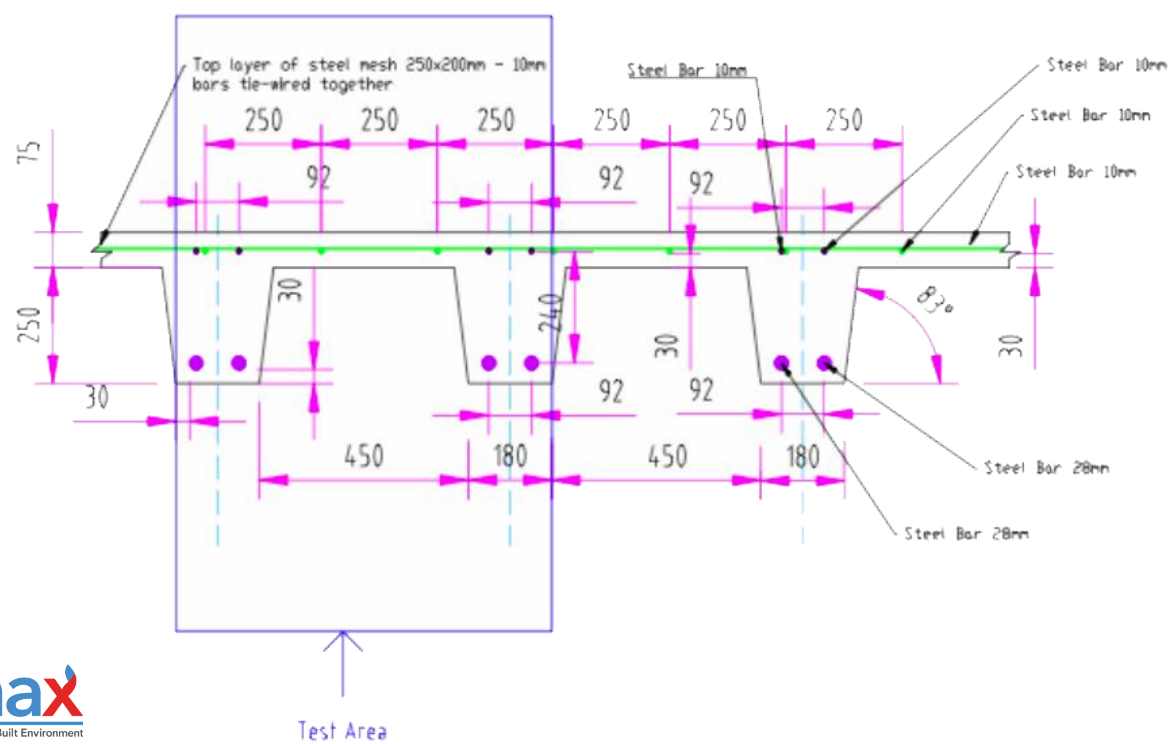
In Australia, there are an ever-increasing number of heritage listed buildings that require upgrades to their fire protection performance. Usually, these buildings are made up of traditional materials such as masonry, brick and other forms of durable construction. As these buildings age and undergo general wear and tear, even the most durable and well design features will need to be replaced or undergo a building upgrade. A typical heritage restoration project can consist of a complete overhaul, or upgrade of select features such as concrete repair and repainting, with the goal of addressing structural compliance and aesthetics of the building.

Heritage buildings are loosely defined as any building or structure of significance for its historic, cultural and aesthetic values. As with most heritage listed buildings, the retention of the subject site façade and purpose following any upgrade work is significant and influential to planning and carrying out restoration works.

The emergence of a need to restore a heritage listed building to meet the modern fire and structural performance standard is the reason behind the need to develop a one-off compliant and effective fire engineered solution. PERMAX has partnered with FERM Engineering, Tremko-Illbruck U.K and Exova Warringtonfire to devise an effective, fire engineered solution to a 13 level, architecturally significant office building in Sydney's CBD. The building was built in the early 1930s and classified as a Class 5 office, thus requiring various structural upgrades to satisfy the NCC Section B. The existing slab structure, defined as a coffer waffle-slab system is doubtful to meet a modern fire performance requirement. This resulted in a collaborative effort to study and model the slab's structural and thermal properties, the result of which were multiple solutions, tackling the scenario of sprinkler-failure in deemed to satisfy and performance-based cases.

PART 2 – THE INTRICACIES OF A COFFER SLAB

Coffer-waffle slab systems are used to serve a dual purpose, to reduce the relative thickness of the slab in very long spans, thus saving cost on concrete and reinforcement, and to achieve an architectural effect. Many coffer-waffle slabs designs are still being used today, to reduce the profile of very deep beams. The coffer-waffle slab system used in this heritage building case study can be seen in the pre-design preliminary sketch below:



Most of the details shown in the sketch were unknown during pre-design and were inferred based on general building trends of the 1930s era. The thickness of the slab was measured, the waffles are approximately 75mm thick, while the beams were up to 325mm deep. The actual cover depth of the reinforcement was unknown, and remain largely inconsistent, and in some cases the reinforcement can be seen exposed to the elements. The challenge of engineers was to specify a suitable cover depth to serve two purposes, for simpler analysis and to recreate an accurate representation of the slab for testing.

Compared to a modern slab, the grade of concrete, slab thickness and reinforcement layout was clearly lacking and needed urgent restoration. The compressive strength of the unrestored coffer-waffle slab was likely 20MPa or less, compared to a minimal 28MPa in a typical modern-day slab. Worryingly, the 75mm depth of the waffles was approximately half the typical depth of a steel deck slab, and up to a quarter the depth of a regular reinforced concrete slab. The reason for the difference in compressive strength was due to aggregate composition. In modern slabs, two types of aggregates are used, coarse aggregates (typically larger than 5mm) and fine aggregates (typically less than 5mm), the concentration and grades of each type in the concrete mixture determines the dry strength and overall grade of concrete. Upon inspection of the heritage coffer-waffle slab, it is obvious that the aggregate size and concentration were poorly graded. This meant that the actual compressive strength and grade of the slab is poor, noting the age, physical appearance and condition of the slab, engineers and architects acknowledge the unreliable features of the slab.

Below: Coffer-waffle heritage slab

Each waffle is approximately 630mm spaced apart centre-to-centre, allowing for minimal reinforcement. Ten (10)mm diameter steel bars are used to reinforce the waffle deck, spaced approximately 30mm from the underside of the slab, however, this was inconsistent as the bars had varying depths. The reinforcement in the beams were two 28mm steel bars, arranged horizontally with a 30mm cover depth from the underside and edge of the beam. The 10mm diameter steel bars reinforcing the waffle were also used, matching the configuration of the waffles. A 250X200mm steel mesh consisted of 10mm bars tied together directly above the 10mm reinforcement bars used, spanning the full length of the beam and slab.

According to current Australian Standards AS3600-2009 [2], concrete slabs serve a dual purpose when fire resistance is concerned. They provide a structural adequacy and/or a separating function. Structural adequacy is the ability of the slab or part of it to fulfill its loadbearing requirement for a specified duration of fire exposure, this is expressed as the first number in an FRL (Fire Resistance Level). Separating functions of the concrete slab are expressed in two ways, the first is integrity where the slab is expected to prevent fire spread by passage of flames or hot gases, the second is the prevention of ignition and critical thermal transfer of heat beyond the exposed surface, referred to as insulation. Integrity and Insulation are the second and final value in an FRL, respectively.

Fire protection is equally important to concrete slabs and other structural components including steel beams and columns. Similarly, concrete slabs are prescribed a period of fire resistance in minutes commonly referred to as the FRL. These periods can range from 30 minutes to 240 minutes, depending on the Class (purpose and location) of the slab. The FRL of modern slabs can be determined using Table 5.4.1(A) of AS3600-2009 [2], and the FRL requirements of various structural components including concrete beams and slabs are detailed in the NCC 2016, BCA Volume 1.

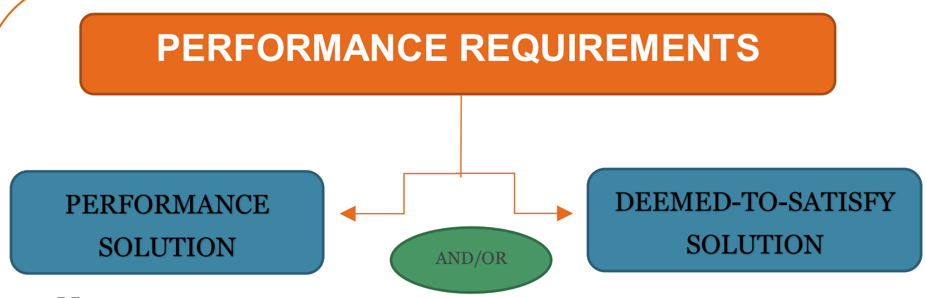
Based on the current condition of the coffer-waffle slab, fire and structural engineers determine that the existing FRL is 75/75/75 minutes, meaning the heritage slab has a minimal existing structural adequacy, integrity and insulation fire resistance level of 75 minutes.

PART 3 – CONSIDER THE MODERN NCC

The process of modern PFP (Passive Fire Protection) involves structural-fire engineering and the application of "fit for purpose" PFP products to meet a specified FRL. The requirements for this process is based on the National Construction Code (NCC) [3] which was formally adopted in 1988. Prior to 1988, several existing government entities were superseded by the formation of the NCC [3]. It was not until 1998, ten years after the adoption of the NCC [3], when performance-based solutions were introduced to the Building Code of Australia (BCA) and adopted by states and territories in the Commonwealth.

In the period up to 1997, Australian fire safety design were dependent on compliance with the prescriptive Deemed-To-Satisfy (DTS) requirements of the BCA. The adoption of performance-based design practice give flexibility to fire engineers, allowing for modern approaches to satisfy the new provisions of the BCA and make great improvements to the design of buildings.

PERFORMANCE BASED SOLUTIONS



Note:

The term *Performance Solution* was formerly known as *Alternative Solution*.
The terms *Performance Solution* and *Deemed-to-Satisfy Solution*
were formerly used under the term *Building Solution*.

The result of these changes culminated in better engineering design, visually appealing examples include the One-One-One Eagle Street building in Brisbane and the NAB building in Melbourne.

Unfortunately, the same design flexibility used in modern buildings cannot be replicated for heritage buildings whose design did not rely on performance-based solutions, but rather strict prescriptive codes that are long outdated. Comparing the two approaches side by side immediately reveal the radically differing requirements. In many cases around Australia, heritage listed buildings are increasingly identified as under-designed, as they fail to meet current Australian Standards in both DTS and performance-based requirements.

The goal of this coffer-waffle heritage upgrade will be to combine the flexibility performance based design, but retaining the structural elements and character that were designed last century via a prescriptive approach. One of the challenge will be to prove that any design enhancement, will be able to meet the required fire resistance level in a performance-based design.

Clearly, one of the main challenge for any heritage upgrade project, is to meet the rigorous demands of a modern fire code while retaining as much of the existing structural elements and décor as possible.

NCC ASSESSMENT

The initial challenge to engineers on the project was to define the FRL levels for a building built in the 1930's.

NSW legislation allows assessment paths to meet modern codes in the development application.

The design and assessment carried out by FERM Engineering allows the fire rated floors to improve the level of fire safety, which is achievable with the Nullifire SC902 intumescent system.

The agreed FRL was selected based on three provisions:

Existing (75/75/75)

Performance (90/90/90)

DTS (120/120/120)

The final proposal provided two options for a (90/90/90) performance based FRL and a DTS provision of (120/120/120).

Stickability – the adhesion duration of intumescent, was tested for Nullifire S707 waterborne intumescent on a previous project – The Brisbane City Hall upgrade.

The tests showed that the stickability of waterborne intumescent was adequate for a heritage concrete slab to achieve an FRL of 45/45/45.

PERMAX© found that during indicative tests with Nullifire SC902 on concrete that the hybrid intumescent had much greater stickability than waterborne intumescents such as Nullifire S707.

Thus improves the confidence in the product's ability to achieve higher FRLs.

PART 4 – AD HOC TESTS & CERTIFICATION

To alleviate the unknowns, the design team and fire engineers rely on the collaboration with architects and record keepers to find and fill in the missing information. As most information cannot be fully recovered, some information was interpreted based on the best engineering judgement and historical trends of the 1930s. An example is the strength and composition of the concrete. With experiences working on the Brisbane City Hall restoration project, we discovered that the grade and compressive strength of the concrete slabs were lacking. Ultimately the concrete strength can be as low as 20MPa, with varying grades of aggregates, possibly from sources in the Brisbane River catchment. Extrapolating this information and applying it to other heritages slabs including this example, will hopefully allow for a conservative estimate of the condition and composition of the slab without extracting a physical sample.

Once this information has been obtained, a test sample can be prescribed and recreated accurately to be tested in accordance with the appropriate modern Australian Standards. Only then can any relevant fire engineered performance-based solutions and modelling can be carried out.

The test will mainly look at two criteria for failure:

1) Stickability and,
2) Critical steel and concrete temperature (400°C)

PART 5 – THE PROPOSAL

The building is classified as a Type A, Class 5 construction, requiring upgrades to satisfy the fire performance under Spec C1.1 for NCC [3] Section B. As such, Table 3 from Spec C1.1 of the NCC [3] specify the loadbearing internal floors to have a fire rating level of 120/120/120. (Refer to Appendix B)

Achieving such a high fire rating level is no easy task, it was clear from the beginning that achieving a 120FRL in the 75mm deep waffles was the critical feature. The challenge was to specify a suitable cover depth for the recreated slab as the cover depth reinforcement details of the historical slab were unknown. Based on experience with the Brisbane City Hall slab and average profiles of the coffer-waffle slab, engineers assumed a worst-case scenario and selected 30mm of cover for the recreated test slab.

Based on the judgement and expertise of Nullifire and FERM Engineering experts, the coffer-waffle slab will have two coating thicknesses of Nullifire SC902. The first thickness will be applied to the underside of the 75mm thick flooring, this is considered the critical component of the slab and will have the thicker of the two prescribed thicknesses.

The second area to be painted is the sides and underside of the beam section, which is less critical, denoted as Part B. Both Part A and Part B will have two thicknesses, to achieve a 90 min and 120 min FRL respectively. (Refer to Appendix A)

The heat developing in the steel reinforcement and mesh were used as the input to a thermal model for elevated temperatures of concrete using As3600 [2], as concrete on its own is more difficult to model, the heating of which is much slower than that of structural steel. Using the provided Nullifire SC902 product assessment report BRANZ FAR 3997 [4] supplied by PERMAX©, FERM Engineering adopted a thermal surface condition input for the concrete which forms the basis for the rationalization of dry film thickness.

The SC902 product itself, is fully compliant and tested to Australian Standards, however only for structural steel. For suitability and compliance, SC902 will be tested, along with the slab towards an A2.2 assessments, in order to be assessed as fit for purpose when used in a way to protect the coffer-waffle slab. For the A2.2 Assessment tests, the team undertook a full scale live fire test at Nullifire test labs in Coventry U.K to AS1530.4 [1] and AS3600 [2] using the recreated section detailed in Part 2. The test was prescribed with designs from FERM Engineering and witnessed by Exova Warringtonfire – a national accredited testing authority (NATA). The test results were thermally modelled using one-dimension thermal modelling and compared with empirical and comparative test data outlined in AS1530.4 [1]. The one-dimensional thermal modelling allowed engineers to assess the approximate temperatures at the surface and various steel reinforcement depths of the waffle slab and in the slab beam. Following the methodology of AS1530.4 [1], the results can also be verified under AS3600 [2] for concrete performance.

The test used a 75mm thick coffer slab, with a specified critical failure temperature of 400 degrees Celsius, thus being very conservative as concrete tend to not yield but will instead deflect. The temperature profile of the exposed surface and reinforcement was matched to a suitable steel element with Nullifire SC902 used as the passive fire protection to structural steel.

The two designs are summarized below, where the coffer is divided into two segments, the floor segment (75milimetres thick) and the floor beam (120milimetres thick).

	Fire resistance 90/90/90 FRL	**Fire resistance 120/120/120 FRL**
Floor Segment A 75mm	Adding 60 min FRL = 1.2mm DFT SC902	Adding 90 min FRL = 1.8mm DFT SC902
Floor Beam B 120mm	Adding 60 min FRL = 1.6mm DFT SC902	Adding 90 min FRL = 2.6mm DFT SC902

PART 6 – EX SCIENTIA VERA

The results from the witnessed tests correlates with the data from the one-dimensional modelling and evaluated in comparison with AS3600 Figure 5.9B (Refer to Appendix C) to evaluate the relative reduction in concrete strength at elevated temperatures. In line with the graph in Appendix C, the concrete strength was reduced to 90-100% of the original strength at 400 degrees critical temperature after 120 mins of exposure to a standard fire.

Ultimately, this means that the designed assembly using Nullifire SC902 at the indicated dry film thickness, has the potential to protect the heritage coffer-waffle slab equivalent to a Deemed-to-Satisfy provision of 120/120/120 minutes. This allows the coffer-waffle slab to meet the NCC [3] provisions for the rated floors under Spec C1.1 – Table 3 for type A construction.

APPENDIX A

Below: The underside of a heritage waffle slab, applied with intumescent paint

APPENDIX B

Type A Construction: FRL of Building Elements

Building Element	**Class of Building – FRL (in minutes)** *Structural Adequacy/Integrity/Insulation*			
	2, 3 or 4 part	5, 7a or 9	6	7B or 8
EXTERNAL WALL (including any column and other building element incorporated therein) or other external building element, where the distance from any fire-source feature to which it is exposed is –				
For loadbearing parts				
< 1.5 m	90/90/90	120/120/120	180/180/180	240/240/240
1.5 – 3m	90/60/60	120/90/60	180/180/120	240/240/120
> 3m	90/60/30	120/60/30	180/120/90	240/180/90
For *non-loadbearing* parts				
< 1.5m	-/90/90	-/120/120	-/180/180	-/240/240
1.5 – 3m	-/60/60	-/90/90	-/180/120	-/240/180
> 3m	/-/-/-	/-/-/-	/-/-/-	/-/-/-
EXTERNAL COLUMN not incorporated in an external wall, where the distance from any fire-source feature to where it is exposed is:				
< 3m	90/-/-	120/-/-	180/-/-	240/-/-
> 3m	/-/-/-	/-/-/-	/-/-/-	/-/-/-
Common Walls and Fire Walls	90/90/90	120/120/120	180/180/180	240/240/240
INTERNAL WALLS				
Fire resisting lift and stair shafts				
Loadbearing	90/90/90	120/120/120	180/120/120	240/120/120
Non-LoadBearing	-/90/90	-/120/120	-/120/120	-/120/120
Bounding public corridors, public lobbies and the like				
LoadBearing	90/90/90	120/-/-	180/-/-	240/-/-
Non-LoadBearing	-/60/60	/-/-/-	/-/-/-	/-/-/-
Between or bounding sole-occupancy units				
LoadBearing	90/90/90	120/-/-	180/-/-	240/-/-
Non-LoadBearing	-/60/60	/-/-/-	/-/-/-	/-/-/-
Ventilation pipe, garbage and like shafts not used for the discharge of hot products of combustion				
LoadBearing	90/90/90	120/90/90	180/120/120	240/120/120
Non-LoadBearing	-/90/90	-/90/90	-/120/120	-/120/120
OTHER LOADBEARING INTERNAL WALLS and COLUMNS				
	90/-/-	120/-/-	180/-/-	240/-/-
Floors	90/90/90	120/120/120	180/180/180	240/240/240
Roofs	90/60/30	120/60/30	180/60/30	240/90/60

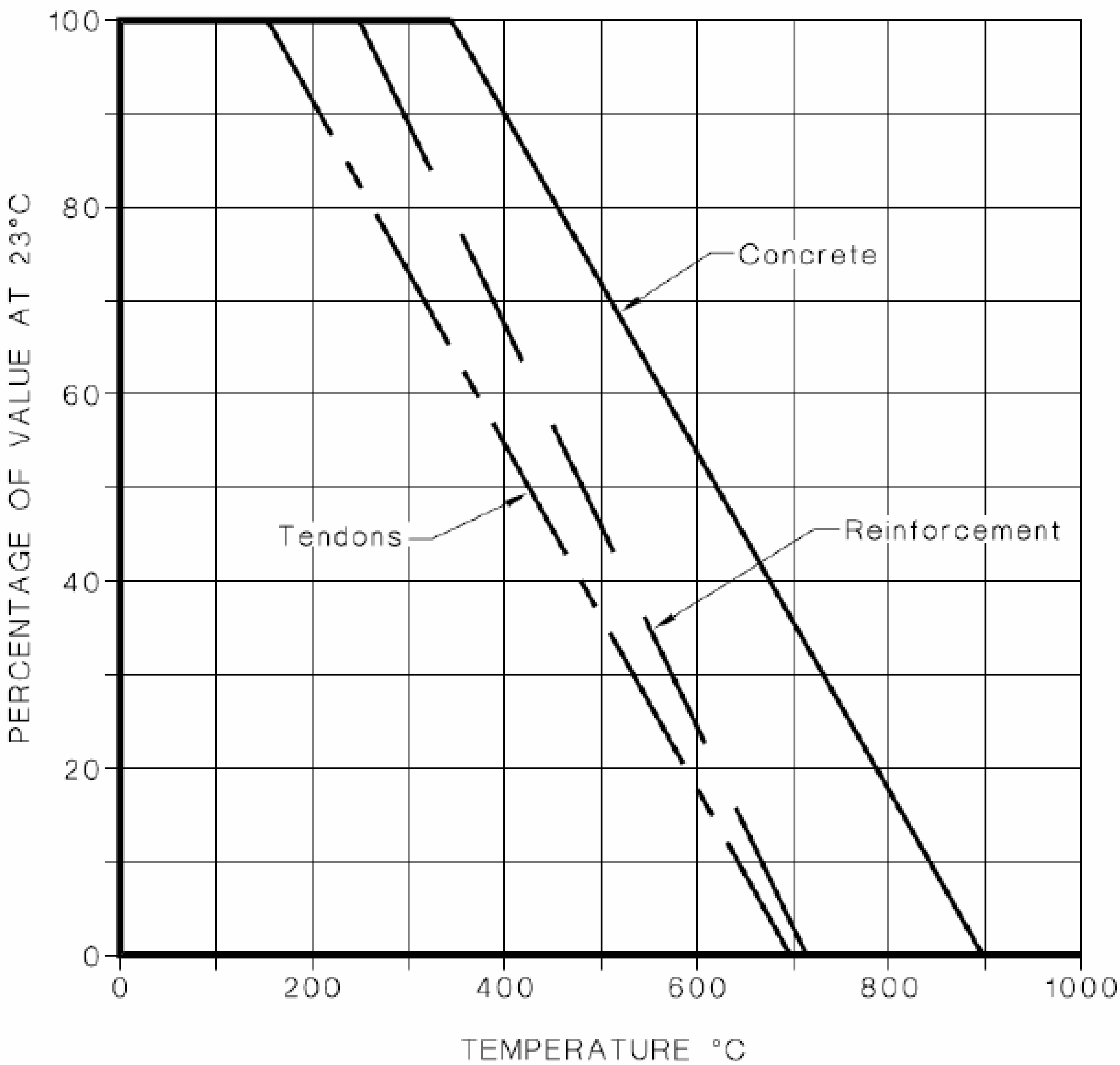


FIGURE 5.9(B) DECREASE OF STRENGTH WITH TEMPERATURE

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