REMEMBERING PROFESSORS PAULAY, PARK AND PRIESTLEY

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ABSTRACT

Professors Tom Paulay, Bob Park and Nigel Priestley each made a massive contribution to structural seismic concrete design both in New Zealand and internationally, receiving numerous international awards and commendations for their research. Alas, all have now passed away and in this article the authors seek to honour their memory and their contribution to the New Zealand concrete industry. The reported information derives from archive material and memories from colleagues and former students, to not only explain the technical contributions of these three great men, but also the mentoring and training that they provided to a generation of civil engineers.

INTRODUCTION

It is quite something to realise that three of the most globally influential structural earthquake engineers of the last 50 years were New Zealanders. Tom Paulay, Robert Park, and Nigel Priestley (pictured in Figure 1) have together revolutionised the seismic design philosophy and way of practice common amongst the global engineering community, with a particular focus on reinforced concrete. Each of them received numerous awards and honours during their lifetimes and each of them had different research highlights and contributions, but a common theme across all of their work was a focus on research that could be used by the engineering industry that derived from strong academic-industry collaboration. This industry engagement was a primary factor to their success, impact and ground breaking research ideas.

Tom Paulay (Reitherman 2006a)

Robert Park (Reitherman 2006a)

Nigel Priestley (Priestley 2015)

Figure 1. The three great structural engineering professors

THOMAS PAULAY

Thomas Paulay or Tamás Paulay was born on the 26th of May 1923 to Margit and George Paulay in his grandmother's house in Sopron, Hungary, a small city at the edge of the Hungarian-Austrian border. Paulay's father George was a cavalry officer in the Hungarian army and as a result Paulay grew up living in a military barracks. Paulay then attended a boarding school for military cadets in Sopron, where he enjoyed the sciences, and later entered the Royal Hungarian Military Academy in Budapest in 1941 at the age of 18 after the start of World War Two (WWII). Paulay graduated from the Academy on August 20th 1943 and was made a second lieutenant in the Royal Hungarian Army, where he was the third cavalry officer since WWI to graduate with distinction. A timeline schematic is provided in Figure 2 of the key events of Paulay's life, along with those of Park and Priestley that are described in the subsequent sections. The timeline provides a means to see what each of these men were doing at the different times during each of their lives.

In June 1944 Paulay was among 24,000 men and 14,000 horses of the Hungarian cavalry division that were sent to fight on the Russian front. In Paulay's words reiterated from the EERI Oral Histories (Reitherman 2006a): "*I was in the war, with my squadron, that had six officers, a captain in charge, and four other officers beside myself, I was second in command… a few weeks later we went into battle and my captain and two other officers of the original six were killed and I was suddenly in command*." At just 21 years of age Paulay was in command of a cavalry squadron consisting of 283 men and 308 horses in the face of the Russian army in the Pripet Marshes of then Eastern Poland. Paulay suffered three major injuries during his service, the first being when shrapnel penetrated his lungs and Paulay was forced to heal in the field with no real medical treatment as they were surrounded by Russians. The second injury was in Warsaw where Paulay was shot in the shoulder with a 20 mm high velocity explosive bullet, with the bullet missing bone by 5 mm, passing through his body, and exploding 15 yards behind Paulay as it hit the earth. The third injury was when Paulay and his men were dug in, using a little farm building as a place to fire their machine gun, and it was struck by an artillery shell causing collapse of the building, which led to partial deafness and temporary paralysis in Paulay's leg. It was at the end of the war whilst helping find shelter for a band of refugees that Paulay met his future wife Herta.

In 1946 Paulay was discharged from the army and he enrolled in a class of 360 students at the Department of Civil Engineering of the Technical University of Budapest. Conditions at the Technical University of Budapest were difficult, as the city of Budapest had been under siege for 52 days during WWII resulting in significant damage to many buildings, including the University's lecture halls. In the EERI Oral History Series on Park and Paulay (Reitherman 2006a), Paulay describes how in the largest lecture hall that he attended a large hole had been blown into the roof which left all lectures at the mercy of the elements. The professors would have to wear gloves and two layers just to write on the board. Additionally, hastily dug graves of fallen soldiers were scattered all over the University campus which Paulay described as "*daily reminders that stifled any temptation to grumble about physical deprivations*." Of all Paulay's classmates from the Military School, a quarter were killed in action in WWII. In 1948 Paulay fled the University after being labelled as a security threat by Communist Hungary in the time of Joseph Stalin, and escaped to West Germany. The story of this escape is rather interesting and the reader is referred to the EERI Oral History Series on Park and Paulay (Reitherman 2006a) for the full details. Unable to continue his studies, Paulay worked for three years at a philanthropic organisation. Whilst in West Germany Paulay reunited with Herta where they married and had their first child Dorothy.

In 1951 Paulay and his family immigrated to Wellington, New Zealand on a scholarship awarded to him by students at Victoria University of Wellington with the help of the International Refugee Organisation. Paulay subsequently got a job with NZ railways in Oamaru, as a maintenance labourer. Finally Paulay achieved his undergraduate degree from the University of Canterbury (UC) in 1953/54 after being admitted as a 3rd year student, in the class two years above Robert Park. For his final structural design examination, the class then taught by Professor Harry Hopkins, Paulay chose to design a reinforced concrete shell roof, which was a subject not covered in the syllabus.

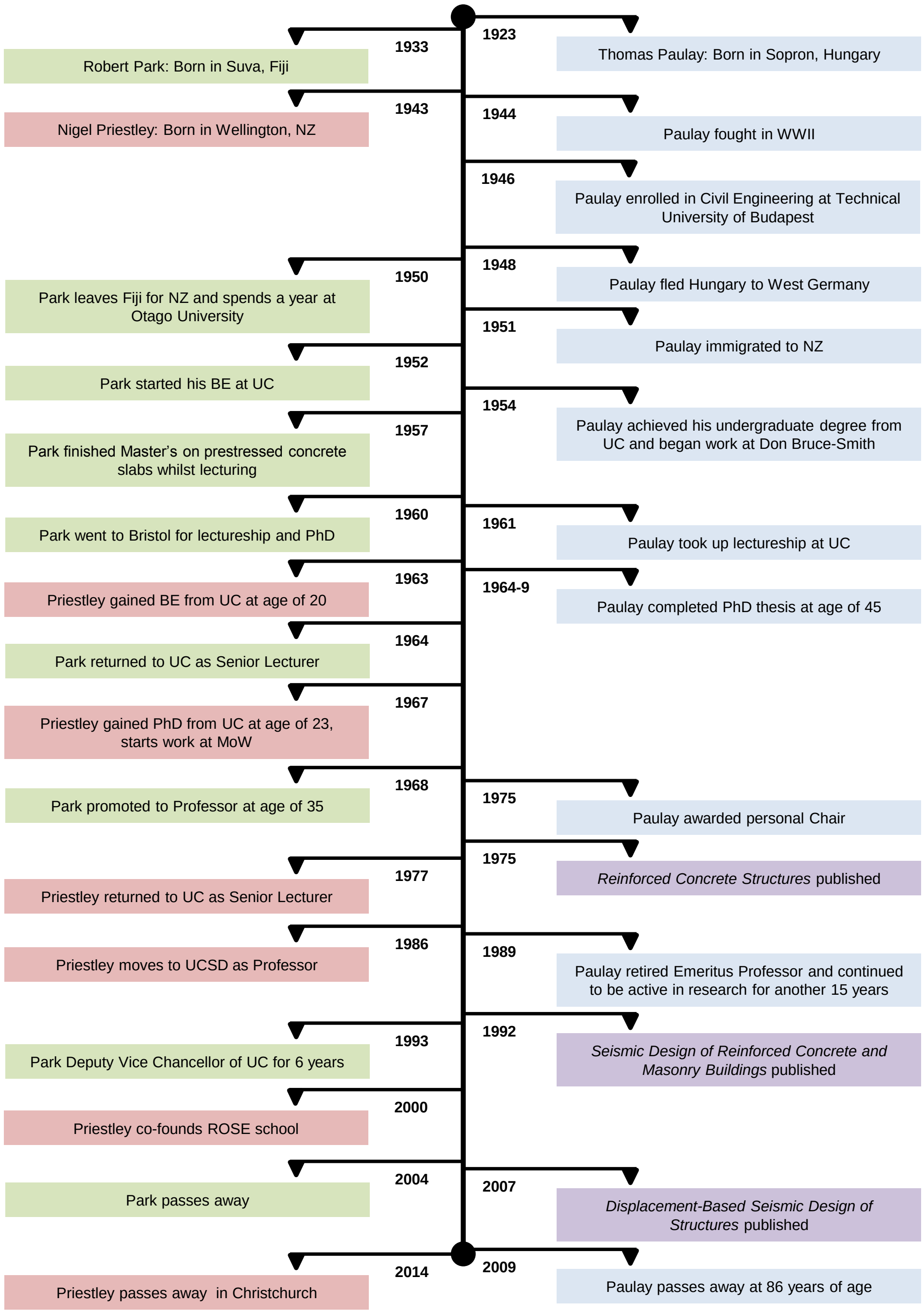


Figure 2. Timeline of key events of all three professors

Professor Harry Hopkins helped Paulay land his first engineering job at Don Bruce-Smith in 1954 where he worked for 8 years. In 1961 Paulay was considering starting his own practice or going into partnership with Don Bruce-Smith, when Harry Hopkins enticed him to return to Canterbury. Harry suggested that he apply for a tenured position with a speciality in teaching structural design, which Paulay followed up and was successful in attaining the position of Lecturer. It was the least remunerative of the career alternatives, resulting in a 35% drop in income at age 37. His desire was mostly to teach structural design, and he had until then given little thought to research. Whilst lecturing in 1964 Paulay began his PhD work on the seismic aspects of coupling shear walls, stemmed from the coupling beam failures observed in the Alaska earthquake of 1964. In 1969 Paulay finished his PhD at the age of 45, after spending several years as a researcher and structural Professor. Paulay's first PhD student was Richard Fenwick, and overall he supervised 15 PhD students and 26 Masters students.

At a symposium dedicated to the lifetime contributions of the two Professors Park and Paulay (Fenwick 2003) Richard Fenwick describes the main contributions of Paulay's work as his teaching and enthusiasm for structural design which was passed onto students who graduated between 1962 and 1989 (>2500 students). Fenwick also identified Paulay's contributions through having a leading role in a team of researchers at UC in which design rules were established for reinforced concrete buildings. Through Paulay's internationally significant work, the status of New Zealand structural engineering was raised through the international reputation he received. Paulay co-authored two definitive texts on the seismic design of reinforced concrete structures with the other two Professors honoured herein. Paulay made major contributions to the New Zealand Concrete Standard in 1982 and 1995, which make up the basis of the current Concrete Structures Standard. Paulay was a fellow of many societies, receiving many awards and numerous honours, including four honorary doctorates, honorary membership of both ACI and IAEE, NZSEE president, and president of IAEE. In 1989 Paulay retired as an Emeritus Professor at UC and continued to undertake research for more than 15 years. Paulay passed away in Christchurch after a year-long battle with cancer on 28th June 2009 at 86 years of age.

ROBERT PARK

Robert (Bob) Park was born in Suva, the capital city of Fiji, in 1933. Park's father, James Tobie McIntyre Park had moved to Fiji from New Zealand to set up a law practice with his wife Loma Twentyman from Australia. Park finished schooling in Fiji at the age of 17 in 1950. Park's main goal after finishing school was to get a higher education and escape Fiji. Park was about 8 years old when Pearl Harbour was attacked during WWII, which illustrates the age difference compared to Paulay who was fighting the Soviets in Europe at the same time. Park was heavily influenced by an uncle who was high up in the Ministry of Works, who was especially proud of a bowstring truss RC bridge he designed in Balclutha.

Park attended the University of Otago first and then UC in 1952, which was where he was introduced to structures and Harry Hopkins initiated his love of concrete. When Park was at UC undertaking his bachelor's degree he was not taught about seismic design. After graduating Park worked at the Christchurch Drainage Board but found it "*very dull*" and was contemplating going for a job in Australia when he went to Harry Hopkins for another matter. Harry enticed Park back to UC to do his master's degree and take up an assistant lectureship. Park finished his masters in 1957 on prestressed concrete slabs, which were intended to be used for bridges, with prestressing being a relatively new technology at that time. During his master's degree Park taught mechanics and reinforced concrete, but it was research that he truly enjoyed. After completing his master degree Park decided to go to England in 1960 to undertake his PhD. Park took up a lectureship at the University of Bristol and completed his doctorate while on the staff, finishing in 1964. Park's PhD was on membrane action in two-way concrete slabs, with a focus on gravity loading only, and ultimate strength theory, i.e. inelasticity, which naturally led into earthquake engineering.

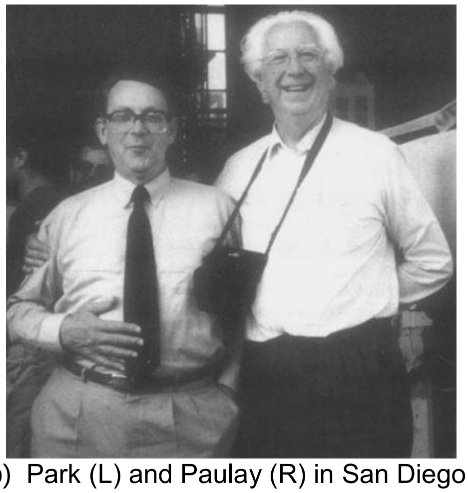
Upon returning to UC Park was hired as a senior lecturer, subsequently promoted to Reader, and then Professor by the young age of 35. Park is pictured in Figure 3(a) studying a beam to exterior column joint during testing at UC. Technically Park's first PhD student was Nigel Priestley, as upon returning from Bristol, Priestley was towards the end of his thesis writing up and had been unsupervised for 18 months. Park's first full PhD student was David Hopkins, and overall he supervised nearly 50 graduate students. Park's research focused on design as it was the final application of the research that Park valued. Park would only be involved in projects that had good design applications. After being the Head of Department for 15 years, Park took on the role of Deputy Vice Chancellor of UC from 1993 to 1999. It is interestingly noted in the EERI Oral Histories (Reitherman 2006a) that Park produced 12 papers per year on average before taking up the Deputy Vice Chancellor role and then this productivity only dropped to 11 per year whilst in the role.

Park's teaching and research work was in the fields of prestressed concrete structures, and particularly the design of buildings and bridges for earthquake resistance. Park was Chair of the Concrete Design Committee of Standards New Zealand. Park served as President of the New Zealand Prestressed Concrete Institute (1975-77) and President of the New Zealand Society for Earthquake Engineering (1983-85), was executive Vice-President of the International Association for Earthquake Engineering (1996-2000), and served as a member on many other international technical committees. Park co-authored "Reinforced Concrete Slabs" with Bill Gamble and the book titled "Reinforced Concrete Structures" co-authored with Paulay. A photo of Park and Paulay together in San Diego in 1993 is provided in Figure 3(b).

Park received 21 prestigious awards from New Zealand and overseas technical societies and institutions for his published papers. Park was invited to become a Fellow of the Royal Society of New Zealand in 1978, and was the first civil engineer to be invited. Park was also invited to become a Foreign member of the Royal Academy of Engineering of the United Kingdom. In 1995 Park received the honour of Officer of the Civil Division of the Most Excellent Order of the British Empire "in recognition of his services to civil engineering." Park received may other distinguished fellowships and honorary memberships; too many to list here.

Park suffered a stroke in 1999 and was not expected to survive, but still managed to resume both his technical and international committee work, despite constraints imposed by partial paralysis of his left side and advice from doctors and wife against international travel, until his untimely death in 2004.

(a) Bob Park inspecting specimen (Reitherman 2006a)



(b) Park (L) and Paulay (R) in San Diego 1993 (Reitherman 2006a)

Figure 3. Bob Park and Tom Paulay

NIGEL PRIESTLEY

Nigel Priestley was born on the 21st July 1943 and attended Wellington Technical College before completing his engineering intermediate year at Victoria University of Wellington in 1960. Nigel gained his BE with 1st class honours from the UC in 1963. Priestley first met Paulay during his 2nd pro year in 1962 when he was one of Paulay's "victims," as Paulay used to call his students (Reitherman 2006a). Priestley met Park four years later in 1966 when Park returned from Bristol and took over the role of supervisor for Priestley's doctoral degree; however this was only in the last months of writing up. Priestley's PhD was on the topic of ultimate strength theory for gravity loads of continuous prestressed concrete beams, and he completed his doctorate at the young age of 23.

After completing his studies Priestley took up the position of Head of the Ministry of Works (MoW) Central Laboratories at Gracefield, Wellington, where he was employed for a decade. During this time Priestley would only see Park and Paulay infrequently at conferences. Due to Priestley's research position at the Ministry of Works he had a lot of contact with Otto Glogau, Chief Structural Design Engineer, and Hanz Huizing, Chief Bridge design engineer. During this time Priestley moon-lighted as a proof engineer for John Hollings' consulting firm (Beca Carter Hollings and Ferner) on a number of their major structural designs and gained valuable design experience doing so.

After working at the MoW for 10 years Priestley was considering joining Hollings' consulting firm full time, to avoid an administrative role he was heading towards at the MoW. However, while attending a NZSEE meeting in Wairaki, Priestley and Park ended up in the same golf foursome during a free afternoon. The other two players were competent and Priestley and Park were not (according to Priestley in the EERI Oral Histories (Reitherman 2006a)). They then proceeded to spend most of the time hacking their way through the rough together. This was interspersed with numerous profanities, and displays of golfing incompetence, and whilst they discussed Priestley's future plans, Park informed him of a faculty position at UC and Priestley was encouraged to apply. According to Priestley, "*up to that point I had not given an academic career a moment's thought.*" (Reitherman 2006a)

After being awarded the position of Senior Lecturer at UC, Priestley spent the next ten years working closely with both Paulay and Park. Priestley was promoted to Reader (Associate Professor) in 1978. The majority of the research was focused on concrete and masonry, and much of the work performed has been incorporated into current New Zealand standards and international codes of practice. Priestley and Park's research aligned well and they co-supervised many students together, investigating such topics as the response of bridges and confinement of concrete.

By the mid-1980s Nigel had gained an international reputation in seismic analysis and design and was lured to a Chair in structural engineering at the Department of Applied Mechanics and Engineering Science at the University of California, San Diego (UCSD). Priestley was president of NZSEE from 1985-86 prior to leaving for California. Priestley remained at UCSD for 14 years during which time his research covered prestressed multi-storey buildings and bridges, culminating in the publication of two books: 'Seismic design of reinforced concrete and masonry buildings' (Paulay & Priestley 1992) with Paulay, and 'Seismic design and retrofit of bridges' (Priestley et al. 1996). After leaving USCD Priestley was a co-founder of the ROSE School in Pavia, Italy and was Emeritus Director, where he taught, advised, and set up courses.

In the EERI Oral Histories (Reitherman 2006a) Paulay described how apparently, when strain gauges were manually read, with four digits called off from each instrument for another person to write down, Nigel could remember previous readings and spot errors in the note book. Paulay described Priestley as a genius.

During Priestley's career he supervised 27 PhD students and numerous ME and MS students at UC, UCSD and the ROSE School. In the 1990's Priestley led the PRESSS Programme and developed the concept of connecting precast concrete components with unbonded post-tensioning. In 2007 Priestley's third text 'Displacement-Based Seismic Design of Structures' (Priestley et al. 2007) was published. Priestley's work on Direct Displacement Based Design (DDBD) is the state-of-the-art book on the topic and DDBD is rapidly replacing the traditional force based design method.

Nigel Priestley had numerous honours and awards bestowed upon him on many occasions. He was an Officer of the New Zealand Order of Merit for services to structural engineering, Fellow of NZ Royal Society, Distinguished Fellow of IPENZ and Life Member of NZSEE, was awarded three honorary doctorates (ETH, Zurich, Cujo (Argentina)), to name only a few accomplishments. Priestley played an important role in the Royal Commission investigating the Canterbury earthquakes, and lead investigations into the collapse of the CTV and Pyne Gould Corporation buildings. Nigel Priestley died on December 23rd 2014 in Christchurch after a long battle with cancer.

KEY INFLUENCES IN STRUCTURAL ENGINEERING

The following section describes the key areas of research and design where Paulay, Park, and Priestley had major influence and impact. The work itself is not cited due to the sheer number of references that would be required. The majority of the research of these three Professors focused on reinforced or prestressed concrete seismic design and the inelastic behavior of concrete structures. Three texts were produced by the three of them that are regarded as the definitive text in the field, these are:

- "Reinforced concrete structures," by Robert Park and Thomas Paulay (Park & Paulay 1975).
- "Seismic design of reinforced concrete and masonry buildings," by Thomas Paulay and Nigel Priestley (Paulay & Priestley 1992).
- "Displacement-Based Seismic Design of Structures," by Nigel Priestley, Gian Michele Calvi, and Mervyn Kowalsky (Hopkins 2003).

It should be noted that other texts were written and published but these three particularly stand out.

It was in the 1960s when Park and Paulay collaborated with consultants on the Bank of New Zealand building in Wellington that they realized that the 34 storey building could not be designed with reinforced concrete to resist earthquakes as not enough was known about the performance of this material. This realization provided a golden opportunity for Park and Paulay to start investigating the main aspects of seismic design related to reinforced concrete. It is of interest to note that in the EERI Oral Histories, Park discussed the importance of the NZ Concrete Society for enabling collaboration between academics and consultants, which brings people together at the Annual Conference, with long talks at the bar into the early hours of the morning.

Capacity Design

Park and Paulay emphasised and promoted ultimate strength design instead of working stress design and were founders of capacity design as an earthquake engineering philosophy. The founding of capacity design was perhaps the area where Park and Paulay were the most influential and had the largest impact on the way structural seismic design is carried out today. Capacity design is a fundamental requirement of NZ seismic design and seismic design codes around the world, and due to the close relationship between Park and Paulay and the local construction industry, New Zealand was the first country to incorporate detailed and specific capacity design requirements in codes. Capacity design is the process by which relative strengths of different members and actions are chosen to ensure that only the designer's intended inelastic mechanism can be developed in a structure during strong seismic action i.e. strong column – weak beam. In the EERI Oral Histories Park describes how the idea of capacity design was really the brain child of John Hollings, who suggested that in order to protect some regions of the structure, they should be made somewhat stronger than adjacent elements. Although, Park does take credit for the reasoning behind the principles of capacity design.

Displacement Based Design

Priestley worked heavily on developing displacement based design and his text on the topic is considered the definitive text. The design method proposed by Priestley is rapidly replacing the traditional force based design method.

Coupling beams

During his PhD Paulay recognized deficiencies in the deformation capacity of the coupling beams of coupled wall buildings and developed the concept of diagonal reinforcement. The goal of his research was to establish an advanced understanding of the behavior of coupled shear wall structures and to be able to produce a method for quick and speedy evaluations that can be feasibly undertaken by structural designers. Paulay finished his thesis in 1969, which extended into studies on the post-elastic behavior of coupled shear walls and their demands and ductility. Paulay concluded that one cannot construct a sufficiently ductile RC link beam between the walls in a conventional manner, no matter how much stirrup reinforcement there is. Subsequently the traditional approach was abandoned, and intersecting diagonal reinforcing bars were introduced. These bars enable the transmission of all earthquake induced coupling beam actions to be resisted by steel reinforcement, with negligible contribution provided by the concrete strength. Once this technique became better known, many friends of Paulay's greeted him from a distance, for example at ACI conventions, by crossing their arms over their heads. It was due to the strong relationship with industry that Otto Glogau, an innovative leader at the Ministry of Works, implemented the innovative design for coupling beams into the Beehive straight away (Reitherman 2006b).

Slabs

Park investigated slabs and produced his text titled "Reinforced concrete slabs" (Park & Gamble 1980). According to Hopkins (Hopkins 2003), Park made yield line analysis comprehensible and capable of application to practical situations.

Frame and wall design and confinement

Some of Paulay's work looked at shear yielding in perimeter frame beams where the reinforcement was bent and crossed at the centre of the beam. Shear failure due to sliding shear in squat walls was also examined. Design methods of confining wall compression zones to improve ductility were established, as were simple rules for determining the design bending moment envelope for multi-storey walls to allow for higher mode effects. Research considering the stability of walls containing plastic hinges led to current requirement in the concrete standard for wall stability. Paulay also found that zones in ductile frames could be minimised by applying moment redistribution. When plastic hinges form in the beams at one or more levels, the dynamic characteristics of the structures are modified and the distribution of moments change, and Paulay established that this behaviour required a dynamic magnification factor due to the higher mode effects.

Throughout their careers the three Professors only ever authored one paper together that Priestley recalls (Reitherman 2006a). Together they identified the mechanisms that resist shear in beam-column joints. They postulated the existence of two shear resisting mechanisms, one involving joint shear reinforcement and the other a linear concrete strut (Paulay et al. 1978) and these provide the basis for current design.

One of Park and Priestley's most well-known articles is titled "theoretical stress-strain model for confined concrete," (Mander et al. 1988) authored along with John Mander who was a PhD student at the time. This work has nearly 2000 citations and marks a great contribution to the basis of confinement design today.

Precast and prestressed structures developing

Park was a key participant in the development of recommendations for the design and detailing of ductile prestressed concrete frames and monolithic precast concrete structures.

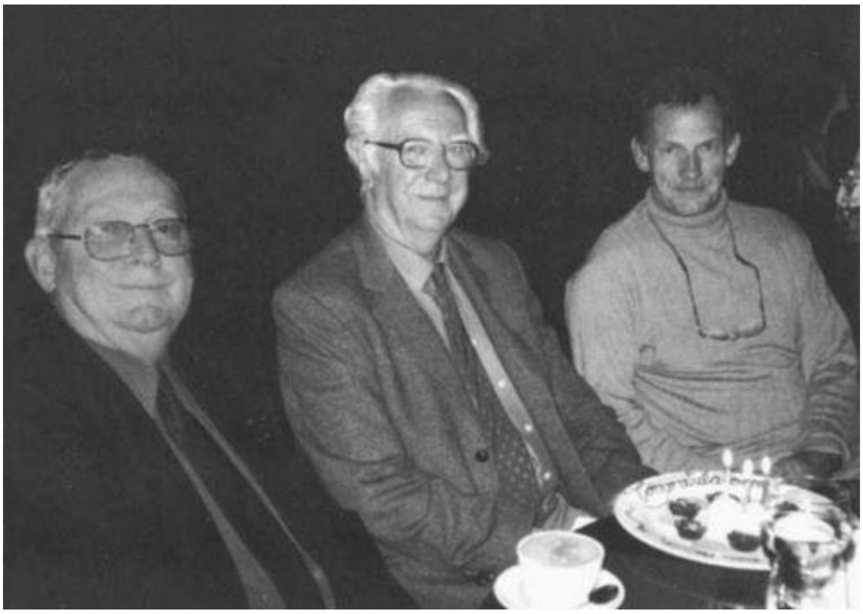


Figure 4. The three Professors pictured together celebrating their collective 200th birthday (Reitherman 2006a)

SUMMARY

The scale of influence that these three professors have had on the world of earthquake engineering and reinforced concrete design is remarkable. Paulay, Park, and Priestley all extended the concepts and practices of reinforced concrete seismic design dramatically and produced definitive texts and publications that are valued around the world. They each contributed significantly to professional committees and code development work that make up the codes we use today. Priestley describes some of Paulay's work as simply elegant and of great significance, and makes one think "*That's so obvious, why did no one see that before?!*" but the same could be said of any of three men's work. They have revolutionised the design of structures to resist earthquakes. These three men made contributions that continue to have a major influence on structural design practice in New Zealand and around the world. All three professors had original and challenging ideas and importantly the ability to transmit these to practicing engineers.

ACKNOWLEDGEMENTS

The majority of the information in this paper was derived from the EERI Oral Histories text and the two papers titled, “The contribution of Tom Paulay to structural engineering,” authored by Richard Fenwick, and “Robert Park – Research contributions from 1958 to 2002” authored by David Hopkins.

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