August 28, 2015

APPENDIX H

OVER FIFTY YEARS OF USING COMPUTERS

The Current Speed of a $1,000 Personal Computer is over 100 million times faster than the $1,000,000 Computer of 1963

H.1 INTRODUCTION

The author first developed a finite element analysis program on the vacuum-tube IBM-701 computer in 1958. Since this computer could only solve forty equations the resulting program was of little practical value. In 1961 the IBM 7090, with a FORTRAN compiler, was used to write the first automated finite element program that could solve practical two-dimensional stress structures. The new numerical methods, the analysis of Norfork Dam with a vertical crack, and a listing of the FORTRAN statements were published as his D. Eng. thesis. The CDC 6400 was installed at the University of California at Berkeley in 1963. The author used this computer for the next 17 years to conduct structural analysis research and to transfer this new technology directly to the profession. Therefore, the speed of the1963 CDC 6400 computer will be used as the reference speed when we evaluate the relative speed of several digital computers built since that time.

H.2 SPEED OF COMPUTERS

In 1956 Professor Steven H. Crandall at MIT in his pioneering book "Engineering Analysis – a survey of Numerical Methods" introduced the concept of numerical operation count as a method of comparing different numerical methods .Basically he defined the evaluation of the following equation as one operation:

$$A = B + C \times D \qquad \text{Definition of one numerical operation}$$

Using double precision arithmetic (14 significant figures), the definition involves the sum of one multiplication, one addition, extracting three numbers from high-speed storage, and transferring the results to storage. In most cases, this type of operation is within the inner DO LOOP for the solution of linear equations and the evaluation of mode shapes and frequencies. Table H.1 indicates the speed of different computers used by the author during the last 50 years.

Table H.1 Floating-Point Speeds of Computer Systems

Year	Computer or CPU	Cost	Operations Per Second	Relative Speed
1963	**CDC-6400**	**$1,000,000**	**50,000**	**1**
1974	CRAY-1	$4,000,000	3,000,000	60
1981	Vax. Or Prime	$100,000	100,000	2
1994	Pentium-90	$5,000	4,000,000	70
1999	Intel Pentium III-450	$1,500	69,000,000	1,380
2006	AMD 64 Laptop	$2,000	400,000,000	8,000
2009	Min Laptop	$300	200,000,000	4,000
2010	2.4G Hz Intel Core i3 64 bit Win 7 Laptop	$1,000	0.77 Billion Compaq Fortran	15,000
			1.35 Billion Intel Fortran	27,000
2013	2.80 GHz 2 Quad Core 64 bit Win 7	$1,000	2.80 Billion Parallelized Fortran	56,000
2015 The cost of one operation has been reduced by over100 Million since 1963				

Because different FORTRAN compilers and operating systems were used, the speeds presented can only be considered accurate to within 25 percent. This increase in computer speed and decrease in cost should not be compared with Moore's law (1965) which estimates the speed of computers will double every 18 months. The number of cycles to perform 64 bit floating-point operation is very large and complex compared to normal computer operation.

It is apparent the introduction of parallel-processors in the inexpensive personal computer will, theoretically, increase the speed proportional to the number of processors. In addition, high-speed, addressable memory has decreased in cost and increased in size for all computer systems. Kryder's law (2005) estimates storage capacity will double every 12 months

H.3 COST OF COMPUTERS versus ENGINEER'S SALARY

In 1963 the author completed his D. Eng. degree and joined a structural mechanics research group at Aerojet General in Sacramento, CA. His salary was $12,000 a year and he worked on several Aerospace Projects including the thermal stress analysis of the Apollo Spacecraft. Fifty years later, in 2013, an engineer with a similar background may be paid $120,000 each year. Therefore, the engineer's salary has increased by approximately a factor of ten during the last fifty years. Now we can create a very interesting plot as show in Figure H.1.

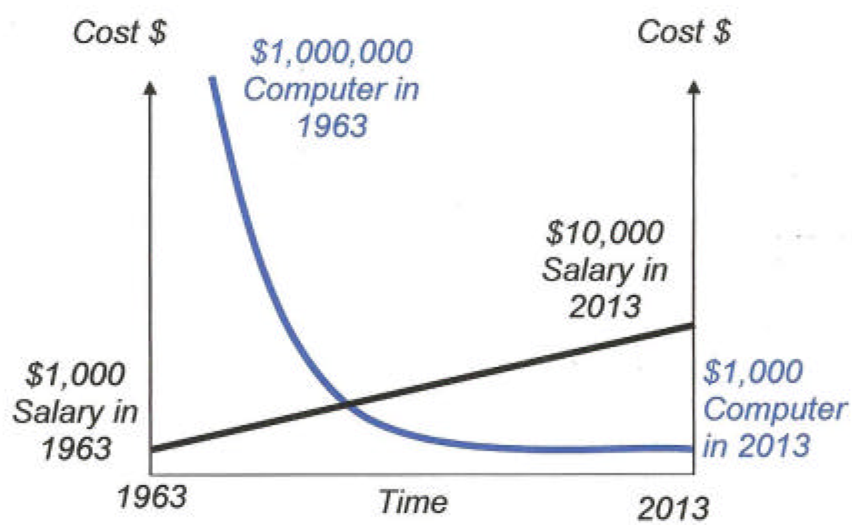

Figure H.1 Cost of Computer Versus Engineer's Monthly Salary

During the past 30 years, the cost of personal computers has been less than one month's salary of a professional structural engineer. At the present time a personal computer, that can analyze large structural systems, costs less than three day's salary. However, if the new computer has a new operating system it may take several days, or weeks, of time to learn a new computer operating system. In addition, your old software may not be compatible with the new system. Often, the cost of new software, compatible with the new operating system, can be more expensive than the new computer hardware.

H.4 IMPACT ON STRUCTURAL ENGINEERING, RESEARCH AND PROGRAM DEVELOPMENT

In 1963 only large companies, government offices and major universities could afford to own a computer. Small engineering offices could use computer service centers where they could pay a fee for every minute they used of computer time to develop their own programs or to use a third-party software product and pay an additional fee to the third-party who developed the program. Plots of the results were normally hand-plotted by the engineer. A few computer centers offered very primitive black and white plotting services for an additional fee.

By 1972 many small offices had rented remote input and output terminals in or near their office. This eliminated very long drives to the computer center. Remote terminal were also used within large organizations to communicate with a central computer center. Computing could be very expensive. This author recalls talking to an employee of Bechtel Corporation and was informed, using an early version of SAP for a three-dimensional seismic analysis of a nuclear reactor, cost $10,000.

By 1983 many organizations had purchased or rented multi-user mini-computer systems such as the Digital Equipment Corporation's VAX or the Data General's PRIME which cost approximately $200,000. They were relatively slow when several engineers were using the computer at the same time; however, overnight runs executed at approximately the same speed as the CDC 6400.

In 1980, however, the author purchased a personal computer, in kit form, for $5,000 based on the Intel 8080 chip and the CP/M operating system. He intended to use to as a remote terminal in his home to access, over low speed telephone lines, all the different computers on campus and to communicate directly with computers located in professional structural engineering firms.

Also, Microsoft Corporation had written a FORTRAN compiler that was compatible with the home computer and the CPM operating system. After personally writing a communication program and a full screen editor in FORTRAN, the smart terminal proved to be a very productive tool for research, teaching and consulting. Most of the time, this FORTRAN compiler for this 8 bit micro computer system was actually faster in compiling software than the $200,000 VAX located on the Berkeley campus. This was because the speed of the VAX was very slow during the day when most of the students were using the computer; whereas, the single-user personal computer executed at the same speed 24 hours a day – 7 days a week.

On this inexpensive computer it was possible to develop a completely new program called SAP 80. It was then possible for an engineer/programmer to increase their research and program development speed by a factor of ten. By 1983 the new SAP 80 program, based on new numerical methods and finite elements, had the same capability of the obsolete main frame structural analysis program SAP IV which was developed by the author and several students over a five year period (1970 to 1975). Without using one FORTRAN statement from SAP IV, one individual (working part time in a home office) developed a new powerful computer program within a two year period. Therefore, the long nights and weekends at the campus computer center immediately ended. Also, large decks of cards were replaced by inexpensive floppy disks.

In 1983, IBM developed a personal computer with Microsoft FORTRAN, floating point hardware and a standard Disk Operating System called DOS that was supported by Microsoft Corporation. It sold for less than $3,000. This allowed other hardware companies to make computers based on the new Intel 8087 chip and the DOS. It was at that point in time the author and a former student, Ashraf Habibullah, President and CEO of CSI, realized that expensive large computer systems would soon be obsolete and all the new development of SAP80 and ETABS series of programs would be for personal computer systems. Also, after the initial investment in software, the professional structural engineers would no longer have to pay for each time they ran an analysis.

H.5 GRAPHICS, STORAGE CAPACITY, PRE AND POST PROCESSING, DESIGN CHECKS, AND MUTI-PROCESSORS

The development of accurate numerical methods for the static and dynamic analysis of complex finite element systems is the area of research and development of this author. He received significant recognition from many engineering organizations for his research and development contributions. However, in 1983 he realized that in order for his work to be of value to the structural engineering profession a significant amount of additional program development must be conducted. The programs must be continually modified in order to take advantage of changes in hardware and new numerical methods. Also, a staff of talented professional engineers must be employed to support questions from users. In addition, the programs required had to be marketed worldwide. The author realized that Ashraf Habibullah and CSI would be the logical firm to take on this responsibility. Since 1983 this arrangement has proven to be very satisfying for both parties.

By 1985 CSI had added graphic options to verify the input and plot results. The addition of design checks was very appealing to structural engineers. After the release of SAP90 the capacity, speed and many other options were added. Also, animation of displacements, member forces and mode shapes were introduced.

During the nineteen nineties CSI continued to add more users and options to the programs. During this period, the Fast Nonlinear Analysis, FNA, method was developed by the author and used on several major projects in the Bay Area. The FNA method proved to be almost 100 times faster than the “brute force” step-by-step nonlinear method used in other programs. However, it is restricted to the dynamic analysis of structures with a relatively small number of nonlinear elements. During this period the author completed the first edition of the book “Static and Dynamic Analysis of Structures” which presented the theoretical details of the finite elements used in the programs and the numerical details of both the linear and nonlinear analysis.

In the release of SAP2000, the FNA method was included and the program was converted to the Window Operating System. During the past several years, Intel has developed chips with multiprocessor and 64 bit addressing capabilities. Also, Intel Corporation has released a FORTRAN compiler and equation solvers for their new processors. CSI has converted all of its software to take advantage of this new hardware and software

Within the past few years, a very significant and convenient development has been the inexpensive solid-state storage. Slow mechanical disk drives can be eliminated to decrease execution time. Now, it is possible to purchase a USB thumb size storage device for less than $15; therefore, it is possible to store all the digital FORTRAN programs, papers, books, slides and photos produced by the author during the last 30 years on one of these devices – very impressive.

H.6 COMMENTS ON MULTI-PROCESSOR COMPUTER SYSTEMS

In 1975 the author read that a complete 8 bit CPU computer had been assembled on one chip. Furthermore, the price of this massed-produced chip was approximately $100 each. At the same time, a local engineering firm was running nonlinear earthquake analyses of a nuclear reactor, using NONSAP on a Cray Computer, at a cost of $100 per node for each analysis. Therefore, if one could build a multi-processor computer system and assign one CPU to each node and each element it may be possible to satisfy the basic equations of force equilibrium, displacement compatibility and nonlinear stress-strain material properties within each element as a function of time using iteration. These possibilities were informally presented by the author at a US-German conference at MIT in 1976.

In 1983 Intel Corporation developed the Hyper Cube Computer composed of 16 bit Intel 8083 chips and gave it to the Department of Electrical Engineering and Computer Science for evaluation. At the same time, Charbel Farhat was a teaching assistant and was working for a Master's Degree in computer science and a doctor's degree in SESM. After he told me of the existence of the Hyper Cube, we started talking about new numerical methods that were required to effectively use the multiprocessor computer. The approach we used was to divide the finite element system into the same number of sub-domains as the number processors that existed in the computer system. This approach proved to be very successful and can be best summarized by the results shown in Figure H.2.

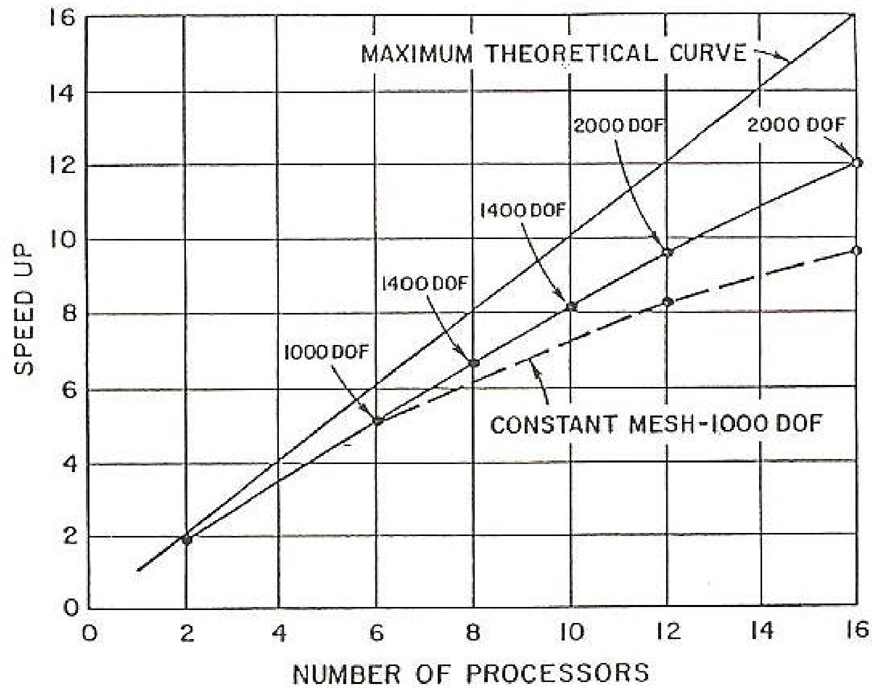

Figure H.2 Speedup Factor versus Number of Processors

The ability to increase the speed of solution to 75% of the maximum theoretical value was very impressive. Details of this early research can be read at the link:

Finite Element Analysis on Multiprocessor Computer Systems

Since Charbel H. Farhat received his Doctor's Degree in 1986 he has pioneered the development of parallel finite element analysis methods for the analysis of fighter aircraft, underwater systems, fluid structures interaction and many other computationally intense complex problems. He has worked closely with the research centers of the Air Force and Navy on the development of many important problems using massively parallel computer systems. He received the USACM John von Neumann Medal. In 2011 he was knighted by the PM of France in the Order of Academic Palms. His engineering contributions have been recognized by his election to the National Academy of Engineering in 2013.

He is currently Professor and Chairman of the Department of Aeronautics and Astronautics at Stanford University.

H.7 The Present (2015) and the Future

The recent introduction of multiprocessors within inexpensive personal computers has energized my old brain to think about the future. Immediately, we can solve our existing problems in solid and fluid dynamics faster and more accurately. Also, it is possible for engineers to start thinking about designing inexpensive structures to resist hurricanes, tornadoes and tsunamis.

In the future every structure will have one or more computers continuously monitoring the current and expected loading on the structure. Based on this information, a smart computer program could direct the structure to adapt the structural elements to resist the expected loading.

However, it appears most young engineers are only interested in using existing computer programs and are not interested in the development of new programs to solve new types of structures that require the development of new numerical methods. Also, all engineers must learn to program these multiprocessor computers and clearly understand the physical equations used within their programs.

Finally a little advice to young engineer/programmers, always give a few of your programs away to show people how smart you are!