

Teaching Modern Concrete Technology at the University of Houston-Downtown

**Jorge Tito-Izquierdo, Alberto Gomez-Rivas, and George Pincus
Visiting Associate Professor/Professor and Chair/Professor and Dean
Engineering Technology, University of Houston-Downtown, Houston, TX**

Abstract

This paper describes a course developed by the Structural Analysis and Design Engineering Technology program at the University of Houston-Downtown to train the students in modern design of concrete mixes. The approach allows students to understand the dynamic nature of the concrete industry and how to adopt new technologies. The course has trained over 150 students that today apply modern concrete technologies at their place of employment.

Students need to understand modern developments in concrete mix design such as: high performance concrete, very high strength concretes, self-compacting concrete, and green concrete among many newer concepts. Students design twenty to thirty different mixes and 400 cylinders are made and tested to verify the design and reach conclusions.

Students measure the physical characteristics of the materials to obtain a mix design with the help of a spreadsheet developed by the faculty. The spreadsheet is based on current recommendations of the American Concrete Institute for the production of trial mixes. Students then mix the materials to acquire hands-on experience on the texture and workability of different concretes. Cylinders are cured and tested at different ages and results are compared with target objectives and with the literature. Incorporation of additives such as silica fume, fly ash, and super plasticizers to arrive at the desired mix characteristics are also investigated.

Introduction

Hydraulic concrete or “concrete” is a mix of different materials, principally Portland cement and other cementitious materials, water, coarse and fine aggregates, and chemical admixtures. Each element has properties which have a particular influence on the behavior of concrete. The interaction between components is also an important topic. In modern concrete industry, it is very important to understand the behavior of each material and the interaction between them, in order to define a better mix design.

The course called Modern Concrete Technology is a new version of the course formerly called Concrete Design. The course is offered to students of junior level standing in Engineering Technology and includes learning about characterization of the components and behavior of concrete for different mix designs, different materials, construction practice, compaction, and

curing in determining the final quality of the concrete. The course is required for students of the Structural Analysis and Design major, but students of other majors, such as philosophy or other engineering technology majors also register for this course, principally because of the practical and hand-on nature of the instruction.

The most important outcome of the Modern Concrete Technology course is the practical experience gained by the students in the development of the mix design, manufacturing, and modern admixtures to obtain the type of concrete necessary for a specific project. The students also develop a critical understanding of concrete behavior because they compare their results with the theory, and with experimental results from other researchers. Knowledge of modern concrete technologies permits significant economies, better quality of the structure, and meeting tight schedules required in the current workplace.

Teaching Basic Concepts of Mix Design

Initial classes of the course are designed to prepare the students with the basics of concrete mix design, principally to understand the properties of concrete constituents. Students learn standard methods for finding material properties. Laboratory work complements the theory and students determine material properties using available equipment. In this stage of the course, the professor defines the specific research for the semester which may vary according to newer findings of the concrete industry, new admixtures used, or a particular topic of interest to the students and professor. The classroom group is divided into teams of four students each and a specific research program is planned for the next several classes. The scientific method for experiment planning is followed so that results obtained by each team are used by all students in preparing each group final report.

The American Concrete Institute (ACI-211.1-91) provides a methodology for design of trial mixes based on the target strength in 28 days (f'_c) which is associated with the water/cement (w/c) ratio, desired workability expressed by the slump of the concrete, maximum aggregate size, use of air-entraining agent, coarse (or gravel) and fine (or sand) aggregate properties such as unit weight, specific gravity, fineness modulus of the sand, and moisture¹. This methodology is presented to the students using examples where they must follow the numerical procedures comparing the results with a spreadsheet called “ACI-Method,” developed in-house using the ACI method. Figure 1 shows the spreadsheet prepared for this purpose. The spreadsheet was designed to include any modification of the theoretical relationships, such as the f'_c vs. w/c ratio, admixtures used, and real proportion per cubic-yard after modifications during mixing. The spreadsheet also computes the cost of the materials per cubic-yard of concrete, which is useful in comparing price versus quality of concrete.

The principal admixture used is a super plasticizer and its weight is adjusted depending on the w/c ratio, other admixtures used, and on the shape of coarse aggregates. The amount of super plasticizer should be in the range recommended by the manufacturer.

A specific mix design is obtained using the ACI-Method spreadsheet in each laboratory session. The properties of the concrete constituents are obtained using experimental methods and are input on the spreadsheet for each specific mix design. Each group of students prepares their

specific mix-design and register in their notebooks the materials used and any observation during mix preparation. The batches are for 12 cylinders of 3-in diameter by 6-in high. These small cylinders are used because they give good results for high strength concrete with small aggregates, and because the batch size is appropriate for hand-preparation. Compression tests are performed each week, typically 2 or 3 cylinders per week up to 28 day old cylinders. The remaining cylinders are tested for tension using the Brazilian Test (Split Cylinder Test). All data is registered in student notebooks and the different teams share their own and other teams' data.

During several years of teaching this course, different investigations were done, for example:

- The first laboratory for each semester is a mix design using the experience of the student group. Generally the students come with some ideas or myths on how to obtain a good concrete and they have the opportunity to test the result. Keeping track of all quantities of materials used initially or added during the mix to obtain their 'ideal' concrete is emphasized. The strengths of these concretes vary from very low strength to normal strength (1000 psi to 6000 psi) depending on the industrial experience of the group of students.
- The Structures Laboratory conducted research for METRO, The Metropolitan Transit Authority of Houston, on the application of fibers to enhance the post failure stability of concrete posts. The research focused on the ability of road markers to survive tire impact. The criterion of satisfactory performance was the ability to keep the original shape after structural failure. Twenty specimens involving different concrete strengths were tested to failure. Half of the specimens were reinforced with fibers, the other half were plain cylinders. Test results indicate for all specimens that had reinforcing fibers increased the post failure ductility of the cylinders. All cylinders that include fibers conserved their structural shape. The plain cylinders crumpled in the form that is well known in testing of concrete cylinders.
- Structural engineers sometimes associate unit weight with strength. "Light concrete = weak concrete" seems to be the axiom. This principle is correct when the aggregate is normal weight because the unit weight indicates the density of the cement paste but when it is applied to light weight aggregate the concept is not valid. Faculty in the Structures Laboratory were interested in using light weight concrete for the very practical reason that elements using light weight concrete are easier to handle. The laboratory manufactured beams ten feet long where the weight difference was significant. Texas Industries has a plant to produce light weight aggregates in West Houston and was interested in supporting research to show that with proper mix design it is possible to obtain high strengths in light weight concrete. For several semesters all mixes used in the laboratory were light weight concrete. Concretes with strengths up to 14 ksi were produced normally and used for beams that were tested in flexure and shear satisfying all strength requirements specified in the code. As a result of these experiences, a light weight concrete prestressed crane was built to manipulate heavy specimens in the laboratory.

COMPANY:	UNIVERSITY OF HOUSTON - DOWNTOWN			HOUSTON, TX	
DESIGN BY:	J. Tito	DATE:	11/11/2004	SUBJECT:	LABORATORY OF
CHKD. BY:		DATE:		CONCRETE MIX DESIGN	SHEET NO. OF
FILE:	C:\Norge\Tito\University of Houston - Downtown\Modern Concrete Program\ACI Method2003			By: Jorge Tito, PhD, PE	JOB NO.

CONCRETE MIX DESIGN

Slump	3" - 4" - 5"	The slump is a measure of the workability; more slump then more workable is the concrete.	
Maximum Size of Gravel	3/8" - 1/2" - 3/4" - 1" - 1-1/2" - 2" - 3"	The range tabulated in this program is from 3 to 20 ksi. Use increments of 0.5 ksi.	
28 days strength, f _c	3 ksi.	NOTE: Use M of gravel <= 3/4 or 1	
water density	62.4 pcf		
spg of cement	3.15	spg = Specific Gravity. From Laboratory Test or Technical Specifications.	
spg gravel	2.60	From Laboratory Test	
spg sand	2.42	From Laboratory Test	
Air Entrained Additives	YES NO	Air entrained additives are used to improve the concrete resistance to extreme cold weather	
Water content	385 lb/cy	From Table 3.4.	
w/c ratio	0.37	From Table 3.5 for f _c to f _{cr} (linear interpolation) 0.37 From Interpolation function	
Cementitious Material	1041 lb/cy	water / (w/c)	
Cement	100 %	1041 lb/cy	
Fly Ash Type I	0 %	0 lb/cy	
Sand Fineness	2.4	From Laboratory Test	
Bulk Volume of gravel	0.59 cu/yd	From Table 3.6 - Maximum size and Sand Fineness vs Bulk Volume of Coarse Aggregate	
Bulk density of gravel	97 pcf	From Laboratory Test	
Weight of gravel	1545 lb/cy		
Super-P Plastizer	0.25 %	Percentage respect to Cement Weight (Follow the Specifications)	
spg of Super-P Plastizer	1.08	From Technical Specifications or Laboratory Test	
Super-P Plastizer	2.6 lb/cy		
Air Volume in percentage	2.50 %	Respect to the Total Volume. From Table 3.4 - Non-Air entrained	
Other Additive 1	0.00 lb/cy		
spg of the Other Additive	1.00	From Technical Specifications or Laboratory Test	
Other Additive 2	0.00 lb/cy		
spg of the Other Additive	1.00	From Technical Specifications or Laboratory Test	

CALCULATION OF THE WEIGHT OF SAND NEEDED

Sand: It is calculated as the difference between the total volume (27 cu) and the volume of all the other materials.

Water	6.17 cu/yd		
Cementitious Material	5.30 cu/yd		
Coarse aggregate	9.52 cu/yd		
Super-P Plastizer	0.0385 cu/yd		
Other Additive 1	0.0000 cu/yd		
Other Additive 2	0.0000 cu/yd		
Air	0.675 cu/yd		
Volume of sand	5.30 cu/yd	27.00 cu/yd	Weight of sand 800 lb/cy

NET INGREDIENTS PER CUBIC YARD (DRY AGGREGATES)

Water	385 lb/cy	
Cement	1041 lb/cy	
Fly Ash Type I	0 lb/cy	
Gravel	1545 lb/cy	
Sand	800 lb/cy	
Super-P Plastizer	2.6 lb/cy	
Other Additive 1	0.0 lb/cy	
Other Additive 2	0.0 lb/cy	
Moisture Content of gravel	0 %	From Laboratory Test
Moisture Content of sand	0 %	From Laboratory Test

GROSS INGREDIENTS PER CUBIC YARD (CORRECTION FOR MOISTURE OF AGGREGATE)

		Price	Commercial Unit		Cost \$/lb	
Water	385 lb/cy				0.001	0.4
Cement	1041 lb/cy	6.47	\$/sack sack = 94 lb		0.06883	71.7
Fly Ash Type I	0 lb/cy	5.58	\$/sack sack = 94 lb		0.059617	0.0
Gravel	1545 lb/cy	3.54	\$/sack sack = 80 lb		0.04425	68.4
Sand	800 lb/cy	2.47	\$/sack sack = 80 lb		0.03088	24.7
Super-P Plastizer	2.6 lb/cy	1.600	\$/55gal-drum 55gal-drm 458 lb		3.49	9.1
Other Additive 1	0.0 lb/cy	9.00	\$/55gal-drum 55gal-drm 458 lb		1.97	0.0
Other Additive 2	0.0 lb/cy	1.800	\$/55gal-drum 55gal-drm 458 lb		3.93	0.0
TOTAL COST:						174 \$/cy

Figure 1. Spreadsheet for Mix Design Using ACI Methodology for Trial Mixes (continued)

MATERIALS FOR LABORATORY

Radius = 3 in
Height = 6 in
Volume = 0.0245 ft³
Waste = 15 %
Volume + Waste = 0.0282 ft³
Number of Cylinders = 12 units

COST = 0.182 \$/cylinder

LABORATORY TEST

ORIGINAL MIX DESIGN			ADJUSTMENT OF THE MIX DESIGN DURING THE LABORATORY							
	For 1 cylinder	For N = 12 cylinders	MATERIAL ADDED TO THE MIX DURING THE LABORATORY	NEW GROSS WEIGHT lb	NEW NET WEIGHT lb	ORIGINAL CY Weight lb	Vol ft ³	Net Weight Per CY lb/cy	Gross Weight Per CY lb/cy	New Cost \$/cy
Water	183 g	2193 g	0 g	21.03	21.03	385	0.17	385	385	0.4
Cement	494 g	5929 g	0 g	50.20	50.20	1041	5.30	1041	1041	71.05
Fly Ash Type I	0 g	0 g	0 g	0	0	0	0.00	0	0	0.00
Gravel	733 g	8799 g	0 g	87.00	87.00	1545	0.52	1545	1545	88.4
Sand	380 g	4566 g	0 g	45.50	45.50	800	5.30	800	800	24.7
Super-Plasticizer	1.2 g	14.8 g	0 g	15	15	2.0	0.04	2.0	2.0	0.1
Other Additive 1	0.0 g	0.0 g	0 g	0	0	0.0	0.00	0.0	0.0	0.0
Other Additive 2	0.0 g	0.0 g	0 g	0	0	0.0	0.00	0.0	0.0	0.0
Air	g	g					0.08			
SUM	1791 g						TOTAL VOLUME (ft ³) = 27.00			
VOLUME	0.0282 ft ³						TOTAL WEIGHT (lb) = 3774 w/c ratio = 0.37			
DENSITY	140 pcf						DENSITY (pcf) = 140			
							New Cost per cy =		174 \$/cy	

Figure 1. Spreadsheet for Mix Design Using ACI Methodology for Trial Mixes (Continuation)

- Use of self-compacting and high strength concrete to cast a reinforced concrete T-beam, which was poured without the use of a vibrator and with smooth finishing. In this case, a special round and small (3/8" maximum size) gravel was used. The sand was coarse, with a modulus of fineness of 3. The w/c ratio and the amount of super plasticizer were initially defined using a trial mix. In this specific case, the concrete had a strength of $f'_c = 10$ ksi with excellent workability. The T-beam was tested by students of the Reinforced Concrete course with results very close to theoretical predictions. Self-compacting concrete is a new technique to obtain a mix that minimizes labor required during field pouring.
- Influence of aggregates on the strength of concrete: different aggregates were used with the same mix design comparing the strength for different ages of concrete (7, 14, 21 and 28 days). It showed that aggregates have special importance for high strength concrete, specifically the strength of the gravel and the bonding strength between gravel surface and the concrete paste. Concretes with strengths between 5 and 12 ksi were obtained.
- Influence of the fly-ash on the strength of concrete: concretes with fly-ash are called "green concrete" because the fly-ash is a residual material from coal combustion, and the fly-ash does not require extra energy to be produced, which makes it very environmental

friendly. Different batches were prepared, one group of students worked with the control mix with cement only (0% fly-ash). The other groups worked with 25%, 50% and 75% of fly-ash type F. Each laboratory session worked with the same mix design according to the desired f'_c only varying the proportion of fly-ash and cement while the other materials were the same, except that the super plasticizer was adjusted to obtain satisfactory workability of the mixes. Figure 2 shows students working on the mix of a concrete with fly-ash. The target strength of the concrete varied from 6 ksi to 12 ksi, and the samples were tested at 7, 14, 21, 28, 35, and 42 days.



Figure 2. Students Preparing the Concrete Mix and Pouring Cylinders

Figure 3 shows a typical compression test. The test frame was built using an in-house design for testing cylinders of 3" diameter, and the jack and hydraulic system was acquired from a local provider. This compression device is significantly less expensive than commercial testing machines and for education, has the advantage that the student can better appreciate the mechanism of load application. Some samples were tested in tension using the Brazilian test (Split Cylinder test), as shown in Figure 4.



Figure 3. Typical Compression Test

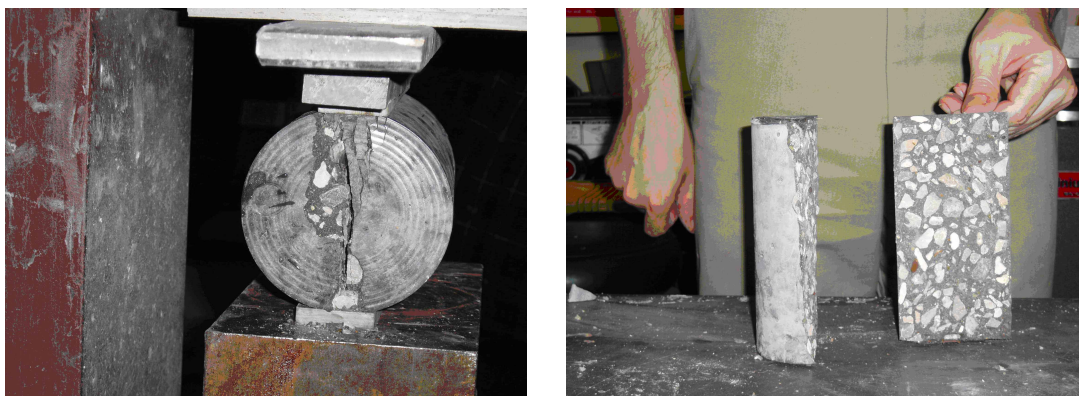


Figure 4. Typical Result of a Tension or Brazilian Test (Split Cylinder Test)

The students observed the importance of fly-ash improving the workability of concretes with low w/c ratio. The amount of super plasticizer used for concretes with fly-ash is lower than for concrete with cement only for the same workability. Other important observation was that the concretes using fly-ash have slower gain of strength than the control mix. The results for 25% fly-ash were very similar to the control mix, but for 50% the strength is reduced considerably but can still be used in the industry, principally because of improved workability. For 75% of fly ash, the strength is very small and use of this proportion is discouraged. An important conclusion of this set of experiments was that the concrete with fly-ash needs more curing time to attain the design value of f'_c , than for normal concrete. It was observed that fly-ash concretes at 35 days were still gaining significant strength, while the normal concrete does not, as shown in Figure 5. This result needs further investigation because it may have an influence on the typical construction specification which standardizes the concrete strength to the results of the test in 28 days. Concretes with a high fly-ash proportion must be tested after more than 28 days of curing in order to avoid conveying a low strength false alarm to the owner, inspector, designer and constructor. In any event, typical structural elements usually take more than 28 days to be fully loaded.

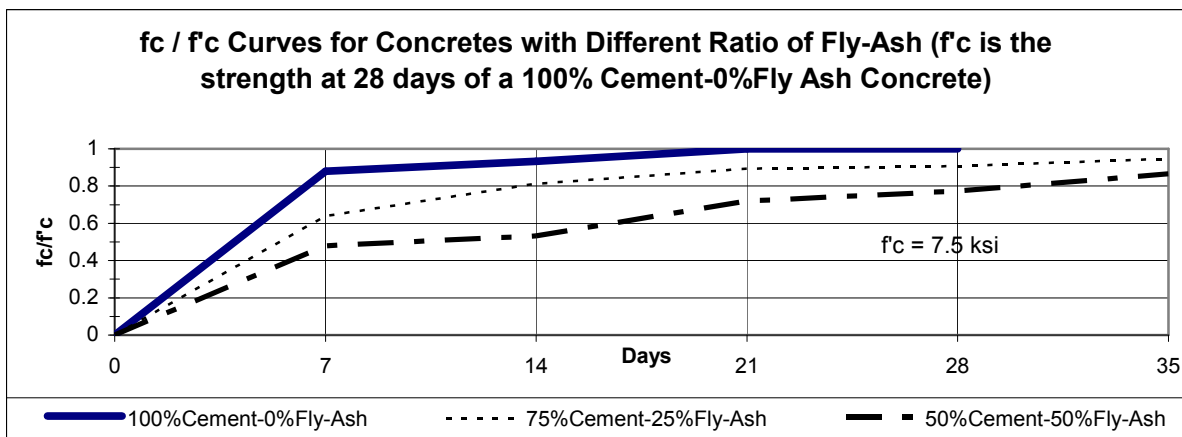


Figure 5. Gain of Strength for Concretes with Different Proportion of Fly-Ash

Finally, a T-Beam was poured using concrete $f'_c = 8$ ksi with 25% of Fly-Ash to help the students of Reinforced Concrete understand the theory explained in other related engineering technology courses. The T-Beam was reinforced with 1-rebar #7 with closed stirrups W4.5 spaced at 4-in. This beam was tested 35 days after casting and the analytical results were in agreement with the experimental test. Figure 6 shows the construction process of the T-Beam.



Figure 6. T-Beam Using Concrete $f'_c = 8$ ksi with 25% of Fly-Ash: Installation of a #7 Rebar; Stirrups W4.5@4"; and Concrete Pouring

- The modulus of elasticity of concrete is measured using a strain gage and a mechanical dial-gage in order to compare results. The students compared the test value of the modulus of elasticity between the statistical equation given by the ACI-318 code ² ($E_c = 57000 * f'_c^{0.5}$) and test values. This type of comparison provides strong support to the theory of reinforced concrete and prestressed concrete. Figure 7 shows the setup used to measure the modulus of elasticity and the stress-strain curve of concrete using both a strain gage and a dial gage. Figure 8 shows the typical curve of stress vs. strain for concrete obtained with this setup. The stress-strain curve was very well defined using strain gages, with better resolution than using the dial gage as expected, but the value of the modulus of elasticity obtained with both methods were similar. The students can then compare these experimentally determined values with the ACI equation.



Figure 7. Measurement of Modulus of Elasticity and the Stress-Strain Curve of Concrete

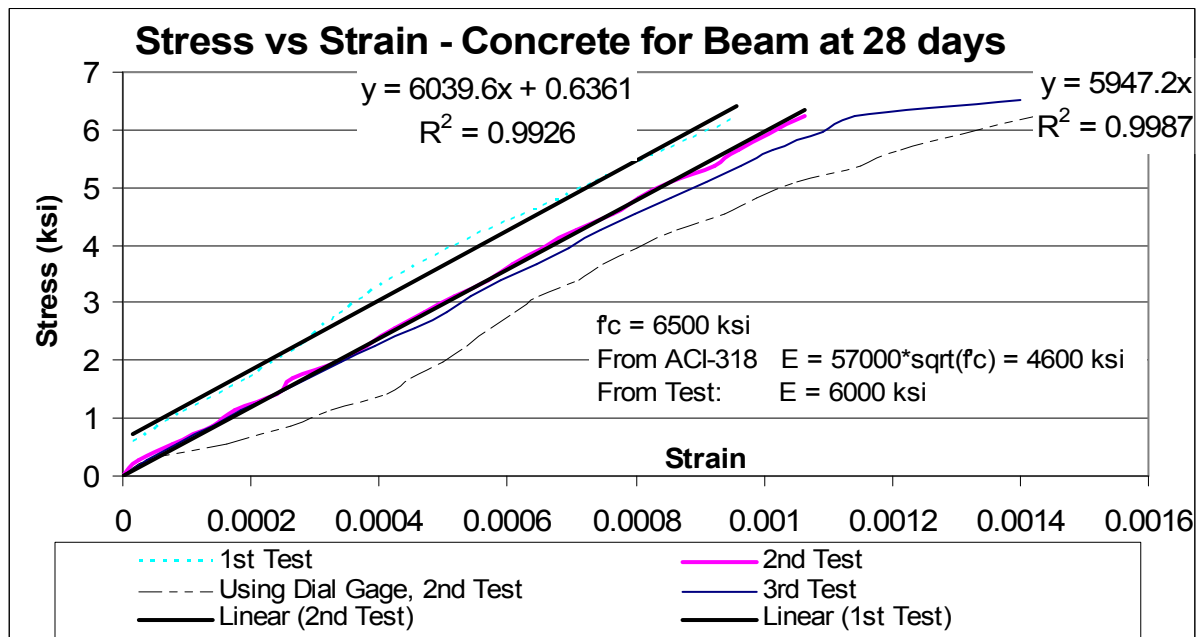


Figure 8. Stress vs. Strain Curve for Concrete Measured Using a Strain Gage and a Dial Gage.

Conclusions

The concrete industry is dynamic and our knowledge and understanding of the behavior of concrete and its constituents continue to improve. The Structural Analysis and Design program of the University of Houston-Downtown recognizes that the students must pursue study of the latest developments of concrete technology and a course was designated for this purpose. The course is “Modern Concrete Technology”, and hands-on student experience is the principal teaching method used by the professors.

Different investigations are performed by students using available materials from the Houston area and important technical conclusions are obtained. These experiences give students valuable knowledge on the behavior of the concrete under different characteristics of its constituents and the importance and role of admixtures to meet specific requirements.

Additional future work will continue to investigate many of the topics described above and others in order to enhance student knowledge in the field of modern concrete design and construction.

Bibliography

- [1] ACI Committee 211, “Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete,” ACI 211.1-91, American Concrete Institute, Farmington Hills, MI.
- [2] ACI 318-2003, “Building Code Requirements for Structural Concrete,” American Concrete Institute, Farmington Hills, MI.

Biographical Information

JORGE TITO-IZQUIERDO

Jorge Tito-Izquierdo is Visiting Associate Professor of Engineering Technology. Dr. Tito-Izquierdo received his Ph.D. and M.Sc. Degrees from the University of Puerto Rico, Mayagüez, Puerto Rico, in Civil Engineering with a major in Structures. He received the Civil Engineer Degree from the Pontifical Catholic University of Peru. Dr. Tito has experience in teaching structural design, and construction management, and is a Registered Professional Engineer.

ALBERTO GOMEZ-RIVAS

Alberto Gomez-Rivas is Professor of Structural Analysis and Chair of Engineering Technology. Dr. Gomez-Rivas received Ph.D. degrees from the University of Texas, Austin, Texas, in Civil Engineering and from Rice University, Houston, Texas, in Economics. He received the Ingeniero Civil degree, with Honors, from the Universidad Javeriana in Bogotá, Colombia. He also served as Chief of Colombia's Department of Transportation Highway Bridge Division.

GEORGE PINCUS

George Pincus is Dean of the College of Sciences and Technology, and Professor at the University of Houston-Downtown (1986-date). Prior service includes Dean of the Newark College of Engineering and Professor, New Jersey Institute of Technology (1986-1994). Dean Pincus received the Ph.D. degree from Cornell University and the M.B.A degree from the University of Houston. Dr. Pincus has published over 40 journal articles, 2 books and is a Registered Professional Engineer.