TranScan

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Crossing Chasms: Concrete Segmental and Cable-Stayed Bridges Do the Job, and Do It Well

A highway bridge can be both striking and awe-inspiring, leaving a lasting impression on the motorists that travel over it and the communities that surround it. But its real value lies in its day-to-day utility and durability, allowing commuters, truckers, families, tourists, and others to safely and routinely traverse a canyon, waterway, or other obstacle—often without even realizing what's below them. There are more than 600,000 bridges in the United States, and keeping them functional and safe is a major job for state and local highway agencies.

A team of US bridge experts (see sidebar) traveled to Switzerland, Germany, Denmark, and France to see what they could learn from their peers overseas about the construction, durability, and maintenance of two types of bridges now routinely being built throughout the United States—concrete segmental and cable-stayed bridges. Representatives from Norway and the United Kingdom journeyed to Denmark and France to join the discussions. The Europeans have a decade or two more experience with these types of bridges, and thus the team was eager to meet with them to learn how well these bridges are holding up; to identify any special requirements for maintenance, repair, retrofit, or replacement; and to compare trends and practice with those in the US.

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Note: affiliations were current as of the time of the scanning tour

Key Findings

"We didn't run into any major surprises on this scanning tour," says team member John Hooks. "Segmental and cable-stayed bridges in Europe are performing well. Any problems with the early-generation bridges have already been dealt with in design guides and codes."

More recently identified problems included corrosion of the reinforcing steel, caused by intrusion of corrosive agents (generally from deicing salts or seawater). This is particularly a problem when the concrete is inadequately consolidated; the voids in the concrete allow seawater and deicing salts to penetrate deep into the slab. A more serious problem occurs when an insufficient amount of grout is pumped into the space around the tendons, allowing moisture to reach and corrode the steel tendons. "This has happened on some bridges

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in Florida," says Hooks, "and it's particularly worrisome because corroded tendons are the precursor to more serious problems, including tendon breakage and even failure of the bridge." These problems can be prevented through tighter quality control during construction.

To enhance durability, most European countries apply waterproof membranes and protective overlays to bridge decks. This is in contrast to US practice today, in which epoxy coated reinforcing steel (rebar), higher quality concrete, and a thicker cover (i.e., more concrete between the rebar and the top surface of the bridge deck) are used, rather than membranes and overlays, to provide the necessary durability.

As in the US, the European agencies add air bubbles to the concrete mix; this air-entrained concrete helps to relieve potentially damaging pressures generated when water that has seeped into the concrete freezes. Fly ash, microsilica, and other materials are often added to further improve durability. Surfaces that are exposed to severe environmental conditions (such as barrier faces) are typically treated with penetrating sealers and sometimes coated with epoxy- or polyurethane-based paints.

New, more robust ducts for post-tensioning systems are being introduced, as are sealed or isolated post-tensioning systems.

Most countries either have or are implementing formal maintenance inspection programs for their bridges. The programs are usually coordinated by a central office or are integrated into a database that tracks bridge maintenance needs and work. The inspection methods and periods vary from country to country. "The countries we visited all seemed very committed to programs and actions that would enhance the long-term durability of their bridges," says Hooks. "Maintenance is a very high priority for them—in fact, higher than what we typically accord maintenance in the US."

As in the US, high-tech materials, such as carbon- and glass-fiber, are increasingly being used in bridge work, particularly for strengthening , repairing, and retrofitting existing structures. Nondestructive inspection methods are being tried, but so far no one has found a simple, reliable method for inspecting post-tensioning tendons or cable stays.

"Both precast and cast-in-place segmental and cable-stayed bridges are proven construction methods for bridges; they are efficient, economical, competitive, practical and attractive, and most designs provide considerable redundancy to withstand extreme or unforeseen events," says Hooks. "These face-to-face discussions and site visits help assure us that we're doing the right thing—that the bridges we build today will stand the test of time, loads, and weather."

Highlights

Switzerland

During their site visits, the team members got a firsthand look at some notable bridges. For example, the striking Salginatobel Bridge in Switzerland (see Figure 1) was one of the first reinforced concrete bridges to be built with an extended span. Constructed in 1929, the bridge was recently renovated and rehabilitated. The pioneering technology that made this bridge possible has been superseded by prestressed structures (see sidebar). Recent studies by the Swiss have found that prestressed concrete structures serve very well. In contrast, several post tensioned concrete decks in Swiss bridges show signs of significant corrosion, the result of chloride infiltration caused by deicing salts that leaked into the joints between deck segments. To prevent such intrusions, waterproof membranes and overlays are typically installed in new construction.

There are now more than two dozen cable-stayed bridges in Switzerland; the oldest was built 38 years ago, but the average age of all Swiss cable-stayed bridges is only 7 years old. There have been no durability problems, nor any vibration problems, with any of these bridges to date. Design is solely the province of the engineer; there are no design standards.

Germany

Germany defines a segmental bridge as one composed mainly of precast concrete segments; by that definition, there are no concrete segmental bridges in that country. The Germans' lack of enthusiasm for precast bridges is the result of concerns

Figure 1. Switzerland's Salginatobel Arch Bridge, built in 1929, has been named an International Historic Civil Engineering Landmark by the American Society of Civil Engineers.

Prestressed Structures

Concrete has a very high compressive strength, but very low tensile strength. By adding reinforcing steel or cables to the concrete, engineers can increase the tensile strength of the concrete; when those rods or cable are then pulled tight (prestressed) within the concrete forms, the concrete becomes stiffer, and the upward force that is generated by the stress acts in opposition to the downward force on the concrete. The result: a stronger bridge deck that is capable of spanning longer distances.

Figure 2. External longitudinal tendons have been retrofitted to the underside of a post-tensioned concrete girder near Cologne, Germany.

about the integrity of the joint between segments, which is considered to be a weak point, allowing water and salts to penetrate and cause corrosion. Older bridges have had problems with cracking at the coupling joints (where the post tensioning tendons were joined). To solve this problem, Germany now requires that no more than 70 percent of the tendons be coupled at one joint, and some older bridges have been retrofitted with external post-tensioning systems (see Figure 2).

The long-term structural performance of decks in Germany is generally good. None have yet had to be replaced.

Denmark

The 20-year-old Sallingsund Bridge, a precast segmental bridge, has required no maintenance to date and shows no signs of problems, according to the Danes. They attribute this to the following factors:

- The membrane prevents moisture from reaching the rebar, despite shrinkage cracks that developed because there was no longitudinal reinforcement.
- The cross fall, or crown, of the bridge deck is maximized, allowing water to quickly drain from the roadway. A waterproof membrane further protects the deck.
- The faces of the joints between segments were sandblasted before the epoxy was applied, and the epoxy was applied to only one face, save for the top 8 inches, where it was applied to both faces. This created a very effective, durable seal.
- Special grouting materials and techniques were used to avoid cross-grouting of ducts in the segment joints.

The cast-in-place Vejlefjord Bridge, which is over 20 years old and carries heavy traffic, had its wearing course completely replaced in 1999; the wearing course is again expected to be replaced in another 20 years. Otherwise, the bridge is holding up very well.

The cast-in-place Alssund Bridge is also performing very well; only minor repairs to the pavement overlay have been necessary (replacement of the wearing course is scheduled for 2006).

Norway

Surveys of Norway's bridges had found evidence of chloride and corrosion problems, even on bridges less than 10 years old. In response, design standards were changed to limit crack widths, increase the amount of concrete cover on decks by 14 percent, and restrict the water/cement ratio to no more than 0.40.

Two bridges, the Puttesund and the Sorsund, experienced excessive long-term deflection at the center hinges of the main-span cantilevers, which resulted in an uncomfortably bumpy ride for motorists. In addition, the deck of the Puttesund bridge was cracked near the quarter points, indicating potential shear problems. Solving these problems involved reducing the weight of the span by replacing concrete sidewalks with aluminum, replacing portions of slabs and surfacing with lightweight concrete, and installing external prestressing.

Concrete Segmental and Cable-Stayed Bridges

Since the early 1970s, hundreds of segmental concrete bridges have been built in the US. These bridges are composed of segments of concrete decking that are either cast in place or are precast off site and then trucked in and installed. Longer spans are made possible by prestressing the concrete, which maximizes the compressive strength of the concrete and helps control cracking and deflection of the bridge deck.

With cable-stayed bridges, the bridge deck is held up by sets of cables that are affixed to towers that rise well above the roadway and are firmly rooted in the ground (see Figure 3). The cables are under tension as a result of being stretched by the weight of the deck and traffic. Compressive forces exerted by the vehicles on the bridge are transferred by the cables to the towers, which then dissipate the forces into the earth.

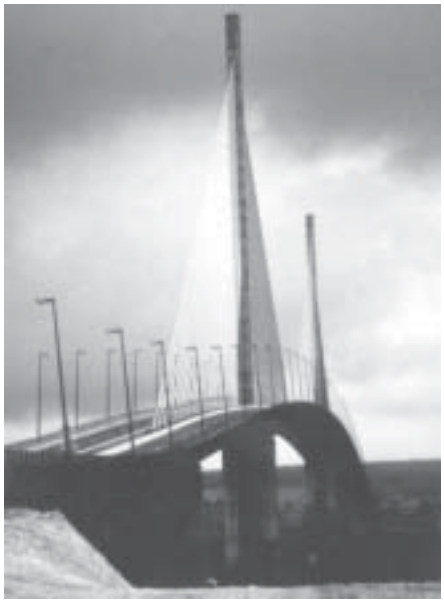

Figure 3. This cable-stayed bridge crosses the River Seine at Brotonne, France.

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France

Almost 20 percent of the bridges on the French highway system are made of prestressed concrete. Many of the older structures have experienced problems, and about 50 have had to be strengthened through the addition of external prestressing tendons.

United Kingdom

A 1992 moratorium on the use of bonded, grouted internal tendons, generated by concerns about defects and damage in concrete bridges, spurred the concrete industry to action. The result was a new design manual for concrete bridges. Studies have since found the UK bridge stock to be in reasonably good condition.

For More Information

For more information about the team's findings, request the complete report, *Performance of Concrete Segmental and Cable-Stayed Bridges in Europe* (Publication No. FHWA-PL-01-019) from FHWA's Office of International Programs (tel: 202-366-9636; fax: 202-366-9626; email: international@fhwa.dot.gov). Or contact John Hooks at FHWA (tel: 202-493-3023; email: john.hooks@fhwa.dot.gov).

Abbreviation Key:

AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
TRB	Transportation Research Board
DOT	Department of Transportation
PIARC	World Road Association
OECD	Organization for Economic Cooperation and Development
IRF	International Road Federation

PIARC Committee Reports

Technical Committee on Economic and Financial Evaluation (C9)

October 29-31, 2001—Coolum, Queensland, Australia

Based on a report by Sherri Y. Alston, Federal Highway Administration

The committee has conducted several surveys to collect information on evaluation methods for road assets, economic evaluation of road maintenance, economic benefits of intelligent transportation systems, costing and pricing principles, and public-private partnerships. The information gleaned from these surveys is being used to develop articles and reports.

The committee's first product, "Transport Costing and Pricing—A Guide to Concepts, Objectives, and Technology," appeared in the April 2001 issue of PIARC's *Routes/Roads*. A committee member wrote an article on private-sector financing of federal trunk roads in Germany, which was published in the July 2001 issue of *Routes/Roads*. These articles, together with other products of the committee, will help road agency staff and others gain a better understanding of road pricing and road financing.

The committee plans to jointly conduct a seminar with the Technical Committee on Performance of Road Administration (C15) in September 2002. The seminar, which will be held in Cuba, is geared for developing nations, particularly those in South and Latin America. It will present information on means of strengthening institutions, managing performance and procurement, and financing road infrastructure.

For more information, contact Sherri Alston at 202-366-9232 (fax: 202-366-7696; sherri.alston@fhwa.dot.gov).

Technical Committee on Urban Areas and Integrated Urban Transport (C10)

Based on a report by George Schoener, Federal Highway Administration, and Ysela Llort, Florida Department of Transportation

The committee has four working groups:

- Sharing the Main Street (Group 1)
- Land Use and Transport Policies in Urban Areas (Group 2)
- Transport Interchanges and Urban Development (Group 3)
- Measurement and Monitoring of Quality (Group 4)

Group 1 is preparing a summary of various guidelines for designing a functional, pleasing main street; the report will also provide examples of good practices. "Main street" is described as that part of the urban area having the following characteristics:

- a variety of buildings serving different purposes and connecting directly to the street;
- both through and local traffic;
- at least one kind of public transit;
- a mix of pedestrian, bicycle, and other slow-moving traffic;
- a traffic level of no more than 50,000 passenger cars daily; and
- a distance of 10-50 meters between opposing building fronts.

The report is expected to be complete by November 2002.

Group 2 is studying an array of urban land use policies and their relationship to urban transportation policies. Group 3 is identifying best practices in integrated passenger interchanges and freight interchanges in urban areas. A summary report, which is expected to be completed late in 2002, will also analyze land use and economic impacts, as well as institutional and financial arrangements in the plan-

ning, construction, and management of these passenger and freight terminals. The report will also include several case studies describing passenger and freight terminals in various countries.

Group 4 is developing a database of indicators used in cities around the world to measure the performance of the transportation system and the effects of transportation policies on safety, the environment, social equity, and mobility. The group's report will include a literature search, as well as case studies; in addition, a seminar on the findings will be presented at the World Congress in 2003.

For more information, contact George Schoener at 202-366-0150 (fax: 202-366-7660; george.schoener@fhwa.dot.gov).

Technical Committee on Earthworks, Drainage, and Subgrade (C12)

October 10-12, 2001—Washington, DC
April 8-10, 2002—Warsaw, Poland

Based on reports by Edward Hoppe, Virginia DOT

The committee's work plan for 2002-2003 includes projects on the following topics:

- Natural materials not compliant with specifications and relevance of earthworks control. Different countries have different approaches to soil classification, including the threshold percentage and grain size for classifying fine-grained soils. Preliminary results from a committee survey have found all countries to be very concerned with the effective control of compaction. Once all survey responses are in, the findings will be published.
- Road embankment construction over soft soils. This project focuses on problems arising from the embankment foundation soils, not the embankment itself. Case studies are being compiled, and the information will summarized in a PIARC report. The committee is considering organizing a seminar on this topic, with Vietnam a likely location.
- Slope risk guidance for roads. Case histories have collected and will be synthesized into a report that is expected to be available in early 2003; the synthesis will include geological information, type of drainage, and potential consequences of slope failure.

The committee conducted a seminar in Ulan Bator, Mongolia, in June, focusing on the appropriate use of natural materials in roads. Topics to be covered include freeze-thaw effects, construction in extremely cold weather, use of marginal natural materials, and erosion control of embankments.

For more information, contact Edward Hoppe at 804-293-1960 (fax: 804-293-1990; edward.hoppe@virginiadot.org).

Technical Committee on Sustainable Development and Road Transport (C14)

June 2000—Helsinki, Finland
November 2000—Madrid, Spain
May 2001—Vienna, Austria
November 2001—New Delhi, India

Based on reports from Shari Schaftlein, Washington State Department of Transportation, and Gloria Shephard, Federal Highway Administration

A working group on decision-making processes in road transport policies, led by Jay Stricker from Australia, has written a report synthesizing a collection of white papers on the topic and incorporating comments from a variety of countries.

A second working group, which is focusing on evaluation and limitation of impacts of road networks and transport policies, has distributed a survey to obtain information on how countries implement sustainable transport policies with regard to health, local pollution, biodiversity, landscape, and vehicle regulation issues. The working group, led by Wilfried Terryn of Belgium, is now compiling the survey responses.

Committee meetings have included presentations on freight transport, sustainable transport, greenhouse gas policies, urban mobility, infrastructure and urban sprawl, environmentally sustainable transport, habitat fragmentation of landscapes, climate change impacts, environmental planning, overcoming institutional barriers to implementing sustainable urban travel policies, clean air and the environment, and highway planning in sensitive areas.

Since 2000, the committee has published three articles in *Routes/Roads:* "European Union Policy on Transport Emissions and Greenhouse Gas," "Greenhouse Gas Policy and the Transport Sector," and "Conducting Sustainable Regional Development Projects." In addition, several papers authored by C14 were included in the proceedings of a seminar jointly organized by the Indian Roads Congress and PIARC. This seminar was the first ever held on sustainability in India.

For more information, contact Shari Schaftlein at 360-705-7446 (fax: 360-705-6833; sschaft@wsdot.wa.gov).

Technical Committee on Performance of Road Administrations (C15)

May 31-June 1, 2001—Rome, Italy
October 29-November 2, 2001—Coolum, Queensland, Australia

Based on a report by Connie Yew, Federal Highway Administration

The committee has developed a framework for describing road network and road agency trends for a range of economic and social systems. The framework is discussed in detail in a paper, "The Economic, Social, and Technical Forces Shaping Road Administration," written by John B. Cox and Miranda Douglas-Crane and published in the July 2001 issue of *Routes/Roads.* It was also presented at the January 2002 meeting of the Transportation Research Board. The paper summarizes the key forces shaping the overall context in which road administrations operate and outlines the range of responses.

Three working groups have been formed to deliver the committee's products:

- positioning of road administrations,
- internal performance, and
- performance management.

For more information, contact Connie Yew at 202-366-1078 (fax: 202-366-3411; connie.yew@fhwa.dot.gov).

Better Ways of Acquiring Right-of-Way

When highway agencies need to acquire land for a new or expanded roadway, the process can be quite sensitive and very involved. The highway agency must first determine the fair market value of the land, and it must then compensate the owner for the taking of the land and bear the cost of relocating affected families and businesses. While the owner seeks to receive the highest value for the property, taxpayers look warily at the highway agency, wanting assurance that it is being fiscally responsible with its money.

To ensure that the public acquisition of private property and the relocation of displaced families and businesses is as fair as possible, Congress enacted in 1970 the Uniform Relocation Assistance and Real Property Acquisition Policies Act; the law was subsequently amended in 1987 as part of the Surface Transportation and Uniform Relocation Assistance Act. The Federal Highway Administration provides guidelines for federal-aid highway right-of-way projects, and many states provide additional guidance. Over the past 20 years, however, the processes of acquiring right-of-way and of accommodating utilities in highway rights-of-way have become more complex as society's needs have grown and as undeveloped land has become more scarce.

To find out how several European countries handle right-of-way acquisition and management, FHWA and AASHTO sent a delegation of right-of-way experts to Norway, Germany, the Netherlands, and England (see sidebar for list of team members). "We wanted to identify practices that when implemented in the US would help ensure timely procurement and clearance of highway right-of-way and adjustment of utilities," says Richard Moeller, co-chair of the scanning team and, at the time, team leader for the technical services group in FHWA's Office of Real Estate Services.

The team was a bit surprised to find that much of the right-of-way acquisition practices mirrored US practice. "But the agencies we visited foster a much stronger sense of community welfare than is typical in the US," says team member Stuart Waymack, director of the Right-of-Way and Utilities Division of the Virginia DOT. "The practices of the highway agencies in all four countries are built on a philosophy of sensitivity to the needs of the property owner, and this often makes detailed regulations on right-of-way appraisals and acquisitions unnecessary."

For example, the highway agency in Norway built a bridge over a new highway solely for the purpose of allowing children to continue to travel safely to a farm for horseback riding lessons (Figure 1). The new highway had isolated the farm from the neighboring community. Even though it would have been cheaper to purchase the farm than to provide the bridge, the highway agency, working with local and national planners, decided that it was important to preserve the farm and its place in the community.

The team also concluded that highway agencies in Germany, the Netherlands, France, and England do a more thorough job of coordinating with the public in matters of land acquisition. The project manager or designer and a member of the right-of-way team meet with affected property owners and conduct a field review early in the development process. They also encourage the property owners to provide input to the design process.

Norway and Germany make use of some form of land consolidation, which allows fragmented pieces of land to be consolidated into a pool for redistribution. Owners receive land that is equal in value to what they contributed to the pool, but that is much more usable and economically rational. This mitigates the impact of property acquisition.

Recommendations

The team members came up with a list of ideas for improving US practice, including the following:

Appraisal and Acquisition

- Involve property owners early on in the design process. This gives the designers information that is crucial to project design decisions, and the result is fewer delays and reduced damages.
- Interview property owners in order to more accurately estimate fair compensation.
- Limit the use of appraisal reviews. Instead of reviewing every appraisal, use

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Note: affiliations shown here were current at the time of the scanning tour

Figure 1. A new bridge reconnects a farm with the neighboring community in Norway.

sampling techniques to monitor the appraisal process.

- Use a single agent for negotiation and relocation activities. This helps maintain a good rapport between the owner and the agency and facilitates consistent, clear communications.
- Adopt special legislation for project development and delivery issues in order to accelerate project completion.
- Use mediation and quick payment processes to speed settlements and payments.

Compensation and Relocation Assistance

- Consider giving special consideration to business owners who are of retirement age and upping the $20,000 liquidation payment to small-business owners. "In England, if a business owner who is being displaced is more than 60 years old, the highway agency will offer to buy the business, so that the owner doesn't have to go through the rigor of moving the business," says Moeller.
- Consider factoring in replacement cost when calculating compensation, as does Norway. The total amount of compensation would include the estimated fair market value, as well as any additional cost to replace the property. Such a one-step process could save time and money.

Training

- Pre-employment degree programs and employee education and training programs should be established for right-of-way professionals. "We need to create a means of providing this information to engineers at the university level, so they bring that knowledge and confidence to the job, rather than having to go through a lengthy on-the-job training program," says Waymack. "FHWA, the International Right of Way Association, and the National Highway Institute offer training programs, but we need to make this an integral part of the engineering curriculum."

Utilities

- Meet regularly with utility company representatives. Many states already have utilities coordinating committees, which are a proven means of enhancing cooperation, coordination, and communication with utility companies.
- Develop and enhance utility pole safety programs, and consider putting utilities underground, as is done routinely in the four countries visited. The additional construction costs could, in many cases, be offset by the benefits to safety, the environment, and communities.
- Consider establishing utility corridors and require utility companies to coordinate the installation of their networks in these corridors. More and more utilities are asking to cross or use highway rights-of-way, so such shared corridors could be more efficient and less troublesome.
- Include utility relocations in design-build contracts. This would reduce delays and help prevent cost overruns.

Changes to US Practices

As a result of the findings from the scanning tour, several states have already modified how they assess and acquire right-of-way and relocate displaced persons and businesses. For example, the Virginia DOT, working with FHWA, developed an experimental tenant relocation incentive program for the Woodrow Wilson bridge project just outside of Washington, DC. "We were 8 months behind in the construction schedule for this massive bridge project," says Waymack, "and we decided to borrow an idea from the Brits—to offer bonuses for tenants who voluntarily moved out early." If they moved out in 30 days, they received a $4000 bonus. If they left between 31 days and 60 days, they received $2000. And if they took the entire 90 days to move out, they were entitled to no additional compensation. "The program was very successful, with 88 percent of the 334 eligible tenants receiving the maximum amount," says Waymack. "And by not further delaying the construction schedule, we calculated that this program saved the Commonwealth of Virginia and FHWA more than $6 million in potential penalties."

Encouraged by the findings of the scanning tour, FHWA developed a national policy on land consolidation, which allows states to acquire property outside the right-of-way limits and then exchange this property for privately owned property that is needed for construction. This technique can be used by any state that wants to consider this type of mitigation for agricultural land or in urban areas. It was first applied in the Interstate 69 corridor.

Four states (Florida, Michigan, Wisconsin, and Washington) are participating in a experiment that eliminates a step in the property valuation process, which is expected yield significant savings in time and cost.

Virginia DOT set up a pilot program to determine the feasibility of paying the preliminary engineering costs for utility

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relocations and found that the benefits outweigh the costs.

In August, FHWA and AASHTO will conduct a 2-day workshop in Baltimore for representatives from 15 states. The first day will be devoted to presentations that are largely based on the findings from the scanning tour, and the second will involve site visits. The three key topics are access management, contractor management techniques, and the role of right-of-way in context-sensitive designs.

For More Information

A summary of the international scanning tour for right-of-way and utilities is available on the Web at international.fhwa.dot.gov. (The complete report will be published later this year by FHWA.)

FHWA's policy on land consolidation is available on the Web at www.fhwa.dot.gov/realestate/mhiaulc.htm.

Resources

Kuala Lumpur: the XXIst World Road Congress, from A to Z is now available. This CD contains 8500 pages of reports from the congress, including 30 introductory session reports, 67 national reports, 162 papers, 10 essays, and 18 activity reports. Information about purchasing the CD is available at www.piarc.org/kl/kl-az-e.htm. General information about the congress, which was conducted by the World Road Association (PIARC), and conclusions from its main sessions are also available on the PIARC web site.

A new OECD publication dispels many of the myths and misperceptions about elderly road users and offers policy and research recommendations to provide for their safe, lifelong mobility. ***Ageing and Transport: Mobility Needs and Safety Issues*** can be purchased at the OECD web site (www.oecd.org).

Safety in Tunnels: Transport of Dangerous Goods through Road Tunnels, another new publication from OECD, proposes an overhaul of risk management systems and the adoption of five categories of hazardous goods cargoes. The report is based on analysis of 33 major tunnel fires that have occurred around the world over the past 50 years. Ordering information can be found at www.oecd. org.

We encourage your comments on the technologies discussed in this issue of *TranScan.* Please send them to:

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