CLIMATE CHANGE IMPACTS ON ASPHALT PAVEMENTS

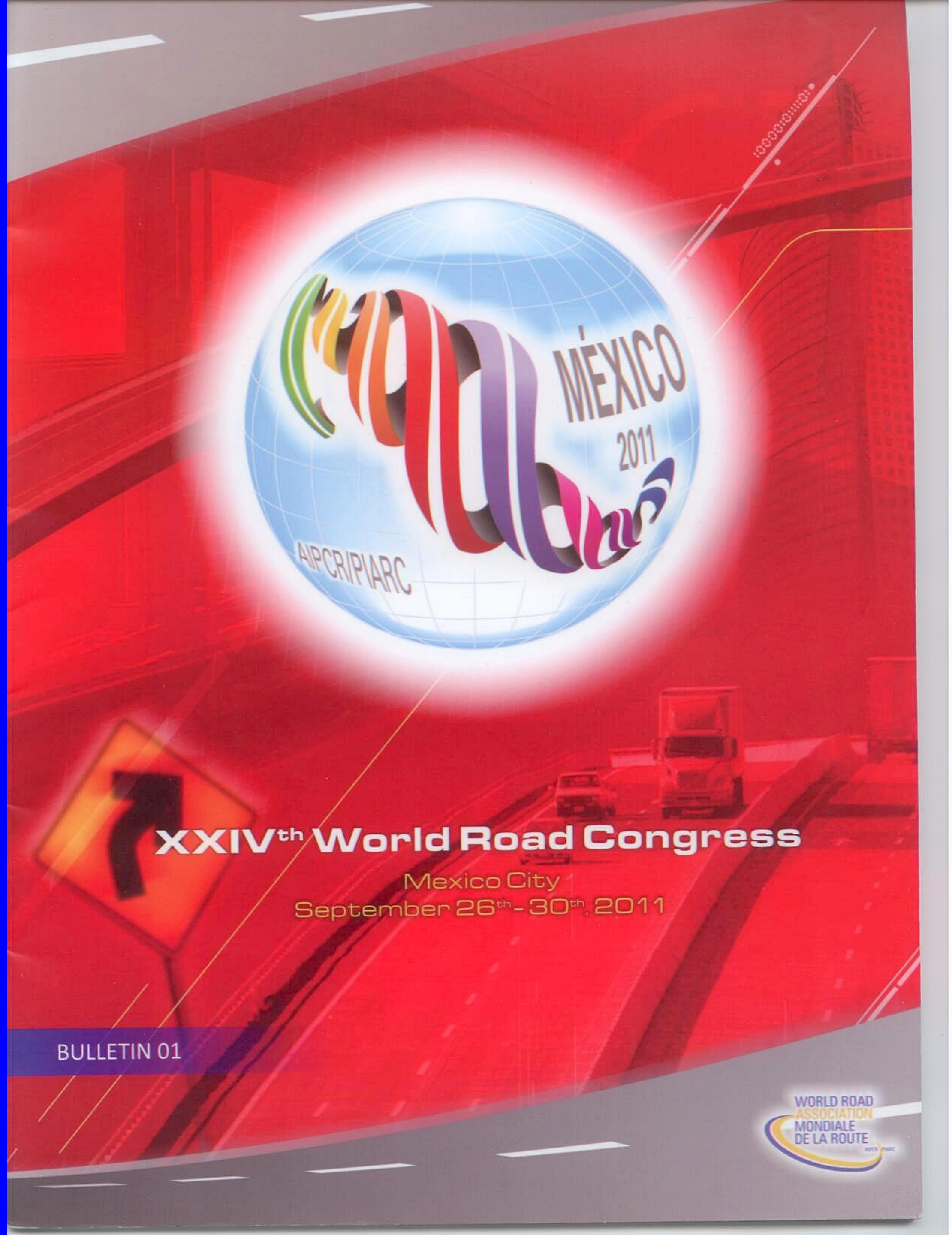
GLOBAL PERSPECTIVE
ADAPTATION AND OPPORTUNITIES
WORLD ROAD ASSOCIATION

JOHN EMERY, PH.D., P.Eng.
CUPGA PAST CHAIR
PRESIDENT AND PRINCIPAL ENGINEER
SHILOH CANCONSTRUCT LIMITED
DIRECTOR, CANADIAN NATIONAL COMMITTEE
MEMBER, WORKING GROUP 5 OF TCD2, PAVEMENTS
ADAPTATION TO CLIMATE CHANGE
HOW TO DEAL WITH EFFECTS OF CLIMATE CHANGE ON ROAD PAVEMENTS
WORLD ROAD ASSOCIATION
ADJUNCT PROFESSOR OF CIVIL ENGINEERING
MCMASTER AND WATERLOO
shilohcanconstruct@gmail.com

THE TECHNICAL ASSISTANCE OF Dr. Peijun GUO, AS PART OF JOINT SHILOH CANCONSTRUCT-McMASTER UNIVERSITY APPLIED RESEARCH ON GREEN PAVEMENT TECHNOLOGY , IS GREATFULLY ACKNOWLEDGED.

SHILOH CANCONSTRUCT IS A SUPPORTER OF THE NEWLY- ESTABLISHED NORMAN W. McLEOD CHAIR IN SUSTAINABLE PAVEMENTS AT THE UNIVERSITY OF WATERLOO.

THE NEXT WORLD ROAD ASSOCIATION (PIARC) WORLD ROAD CONGRESS
WILL BE HELD IN MEXICO CITY, SEPTEMBER 26-30, 2011
ROADS FOR A BETTER LIFE
www.piarcmexico2011.org


MÉXICO
2011
AIPCR/PIARC
XXIVth World Road Congress
Mexico City
September 26th - 30th, 2011
BULLETIN 01
WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE

GLOBAL CLIMATE CHANGE CHALLENGES TRANSPORTATION SECTOR

GLOBAL CLIMATE CHANGE, PARTICULARLY SHORT-TERM (ANTHROPOGENIC), POSES TWO MAJOR CHALLENGES TO THE TRANSPORTATION SECTORS:

1. ENSURING THE TRANSPORTATION INFRASTRUCTURE CAN WITHSTAND THE CLIMATE CHANGE IMPACTS ALREADY IN PROGRESS (ADAPTATION – THE FOCUS HERE IS ON ROAD PAVEMENTS FROM A CANADIAN PERSPECTIVE)
2. REDUCING THE TRANSPORTATION SOURCE GREENHOUSE GAS EMISSIONS (MITIGATION)

CLIMATE CHANGE MITIGATION, WHICH PRESENTS CONSIDERABLE POLITICAL, ECONOMIC AND TECHNICAL CHALLENGES IN CANADA, IS NOT CONSIDERED HERE. ASSESSING THE VULNERABILITY OF CANADA'S ROAD, RAIL, AIR AND WATER TRANSPORTATION INFRASTRUCTURE TO CLIMATE CHANGE IS A KEY STEP TO ENSURING A SAFE, EFFICIENT, SUSTAINABLE AND RESILIENT FUTURE TRANSPORTATION SYSTEM THROUGH TECHNICALLY SOUND, ENVIRONMENT FRIENDLY, ENERGY EFFICIENT AND LIFE-CYCLE COST EFFECTIVE REACTIVE ADAPTATION AND PROACTIVE MITIGATION PRACTICES.

CANADIAN CLIMATE CHANGE TRANSPORATION SECTOR

THE CANADIAN TRANSPORTATION SYSTEM IS WELL DEVELOPED (ROAD SYSTEM ALONE HAS AN ASSET VALUE OF ABOUT $100 BILLION). TRANSPORTATION IN CANADA REMAINS SENSITIVE TO A NUMBER OF WEATHER-RELATED HAZARDS SUCH AS STORM SURGES, HIGH WIND SPEEDS, FOG, HEAVY SNOWFALLS AND ICE STORMS. FUTURE CLIMATE CHANGES PROJECTED FOR THIS CENTURY BY THE IPCC ARE:

1. SURFACE AIR WARMING ESTIMATES FOR A LOW SCENARIO OF 1.8°C (LIKELY RANGE OF 1.1 TO 2.9°C) AND FOR A HIGH SCENARIO OF 4.0°C (LIKELY RANGE OF 2.4 TO 6.4°C), NOTING THAT AS A HIGH-LATITUDE COUNTRY, WARMING IN CANADA WOULD LIKELY BE MORE PRONOUNCED; AND
2. SEA LEVEL RISE ESTIMATES FOR A LOW SCENARIO OF 180 TO 380 MM AND FOR A HIGH SCENARIO OF 260 TO 590 MM.

POSSIBLE IMPLICATIONS OF CLIMATE CHANGE FOR CANADA'S TRANSPORTATION SYSTEM

EXPECTED CHANGES IN CLIMATIC VARIABLES

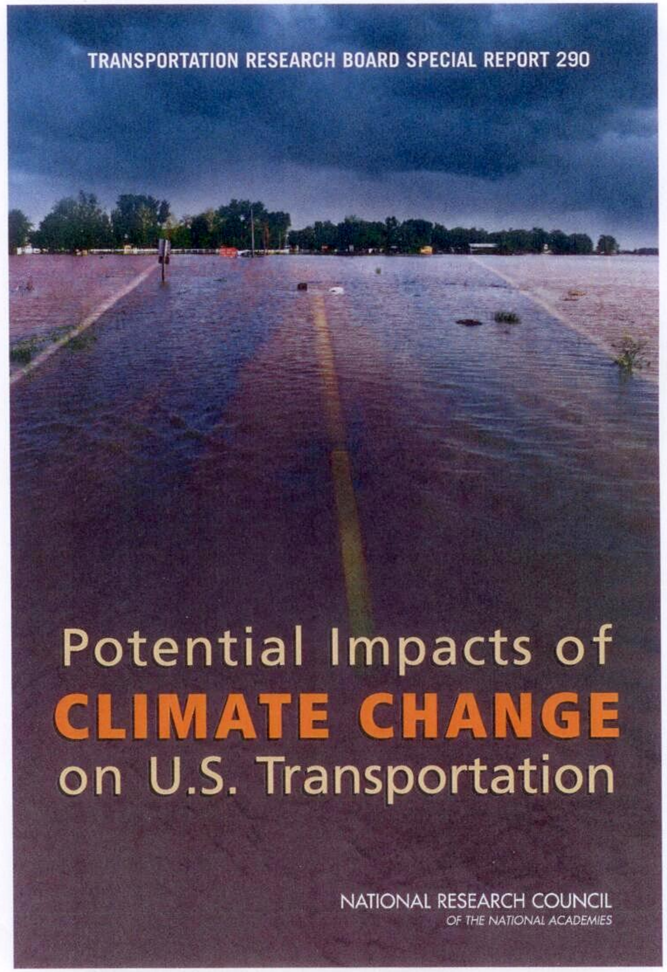
CLIMATE VARIABLE	CONFIDENCE	PROBABILITY
	2001	2007
Increase in mean temperature	**High**	**Virtually Certain, >99%**
Sea level rise	**High**	**Virtually Certain, >99%**
Changes in temperature extremes **(**e.g. increase in summer, decrease in winter**)**	**Moderate**	**Very Likely, >90%**
Increases in intense precipitation events	**Low**	**Very Likely, >90%**
Increase in storm frequency and severity **(**e.g. higher wind speeds**)**	**Low**	**Likely, >66%**
Changes in mean precipitation	**Moderate**	**Likely, >66%**

ADAPTED FROM IPCC

Government of Canada / Gouvernement du Canada

Climate Change Impacts and Adaptation:
A Canadian Perspective

Canada


TRANSPORTATION RESEARCH BOARD SPECIAL REPORT 290
Potential Impacts of
CLIMATE CHANGE
on U.S. Transportation
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

POTENTIAL IMPACTS ON TRANSPORTATION SYSTEMS

NATIONAL

CHANGES IN FUEL EFFICIENCIES AND PAYLOADS
CHANGES IN LENGTH AND QUALITY OF CONSTRUCTION SEASON
IMPACTS ON HEALTH AND SAFETY (E.G. ACCIDENTS, HEAT STRESS, ACCESS TO SERVICES)
CHANGES IN TRANSPORTATION DEMAND AND COMPETITION
CHANGES TO MAINTENANCE AND DESIGN PRACTICES
INUNDATION AND FLOODING OF COASTAL INFRASTRUCTURE

NORTHERN CANADA

INCREASED ARCTIC SHIPPING (NORTHWEST PASSAGE)
INFRASTRUCTURE DAMAGE FROM PERMAFROST DEGRADATION AND INCREASE IN FREEZE-THAW CYCLES

SOUTHERN CANADA

INCREASED COSTS OF SHIPPING IN GREAT LAKES – ST. LAWRENCE SEAWAY SYSTEM
INCREASED LANDSLIDE/AVALANCHE ACTIVITY (E.G. REDUCED MOBILITY, INCREASED MAINTENANCE COSTS)
INCREASED FLOODING OF INLAND INFRASTRUCTURE
CHANGES IN WINTER MAINTENANCE COSTS FOR SURFACE AND AIR TRANSPORT
DECREASED DAMAGE FROM FEWER FREEZE-THAW CYCLES

POTENTIAL CLIMATE CHANGE IMPACTS ON PAVEMENTS

(ASPHALT CEMENT – AC, SURFACE TREATMENT – ST, ASPHALT CONCRETE – HMA, PORTLAND CEMENT CONCRETE – PCC, UNSURFACED/GRAVEL – UG, ICE ROADS – IR)

OVERALL, THE EFFECTS OF WARMING WILL LIKELY BE MORE PRONOUNCED IN THE WINTER THAN IN THE SUMMER.
THE ROAD PAVEMENT IMPACTS WILL GENERALLY ALSO BE THE SAME FOR AIRPORT PAVEMENTS

INCREASE IN THE FRQUENCY AND SEVERITY OF HOT DAY

CHANGES IN PAVEMENT CONSTRUCTION PRACTICE
(E.G. HEAT STRESS, DUST CONTROL, WATER SUPPLY, COMPACTION MOISTURE CONTENT, PCC CURING)
INCREASED THERMAL EXPANSION AND STRESSES
(E.G. EXPANSION JOINT DESIGN, PCC SLAB CURL AND CRACKING, PCC JOINT DESIGN BLOW-UPS)
SOFTENING/INCREASED TEMPERATURE SUSCEPTIBILITY OF AC
(E.G. REDUCED HMA RESILIENT MODULI, HMA INSTABILITY RUTTING, ST AND HMA FLUSHING/BLEEDING, ST AND HMA ALBEDO DECREASE DUE TO FLUSHING/BLEEDING, REDUCED ST AND HMA MICRO AND MACRO TEXTURE DUE TO FLUSHING/BLEEDING)
INCREASED OXIDATION/HARDENING OF HMA ASPHALT BINDER
(E.G. REDUCED RESISTANCE TO WINTER THERMAL CRACKING, INCREASED POTENTIAL FOR TOP-DOWN CRACKING (TDC) OF LONG-LIFE HMA FLEXIBLE PAVEMENTS)
INCREASED OXIDATION/HARDENING DEGRADATION OF CRACK AND JOINT SEALANTS
INCREASED EXTENT AND MAGNITUDE OF URBAN HEAT ISLAND EFFECTS RELATED TO PAVED SURFACES

DECREASE IN THE FREQUENCY AND SEVERITY OF COLD DAYS

CHANGES IN PAVEMENT CONSTRUCTION AND MAINTENANCE PRACTICES
(E.G. LONGER CONSTRUCTION SEASON, LESS POT-HOLE REPAIRS, REDUCED THERMAL PROTECTION)

CHANGES IN THE FREQUENCY OF FREEZE-THAW CYCLES

PREMATURE DETERIORATION OF PAVEMENTS RELATED TO HIGH FREQUENCIES OF FREEZE-THAW CYCLES, PARTICULARLY FOR SATURATED, FROST SUSCEPTIBLE, SILTY SOILS.)

SOUTHERN REGION – FEWER FREEZE-THAW CYCLES RESULTING IN LESS FROST DAMAGE

NORTHERN REGION – MILDER WINTERS WITH MORE FREEZE-THAW CYCLES RESULTING IN DECREASED AVAILABILITY, ACCELERATED DETERIORATION AND INCREASED MAINTENANCE COSTS FOR ROADS THAT RELY ON A FROZEN SUBGRADE FOR STRENGTH, WHICH MIGHT BE PARTIALLY OFFSET BY FEWER SPRING THAWS

REDUCED COSTS AND USE OF ANTI-ICING AND DEICING MATERIALS RELATED TO SNOW AND ICE CONTROL

USE OF PROVEN SOUTHERN REGION WINTER MAINTENANCE TECHNIQUES FURTHER NORTH

PROBABLE REDUCTION IN THE NUMBER OF ACCIDENTS RELATED TO SNOW, ICE AND WINTER STORMS

INCREASE IN ANNUAL PRECIPITATION AND INTENSE PRECIPITATION EVENTS

WITH AN INCREASE IN THE PROPORTION OF PRECIPITATION FALLING AS RAIN RATHER THAN AS SNOW IN THE SOUTHERN REGION. THE TIMING, FREQUENCY, FORM AND/OR INTENSITY OF PRECIPITATION AFFECTS RELATED NATURAL PROCESSES SUCH AS DEBRIS FLOWS, AVALANCHES, LANDSLIDES, MUDSLIDES AND FLOODS.

MORE DAMAGE TO PAVEMENT STRUCTURES AND EMBANKMENTS DUE TO RAINFALL-INDUCED LANDSLIDES (GROUND MOVEMENTS)
(E.G. INCREASED EXTREME RAINFALL AND SNOWMELT-INDUCED LANDSLIDE FREQUENCY IN ALPINE AREAS OF WESTERN CANADA, INCREASED PRECIPITATION-TRIGGERED INSTABILITY OF EMBANKMENTS AND PAVEMENT STRUCTURES UNDERLAIN BY CLAY-RICH SEDIMENTS IN PARTS OF EASTERN ONTARIO AND SOUTHERN QUÉBEC)

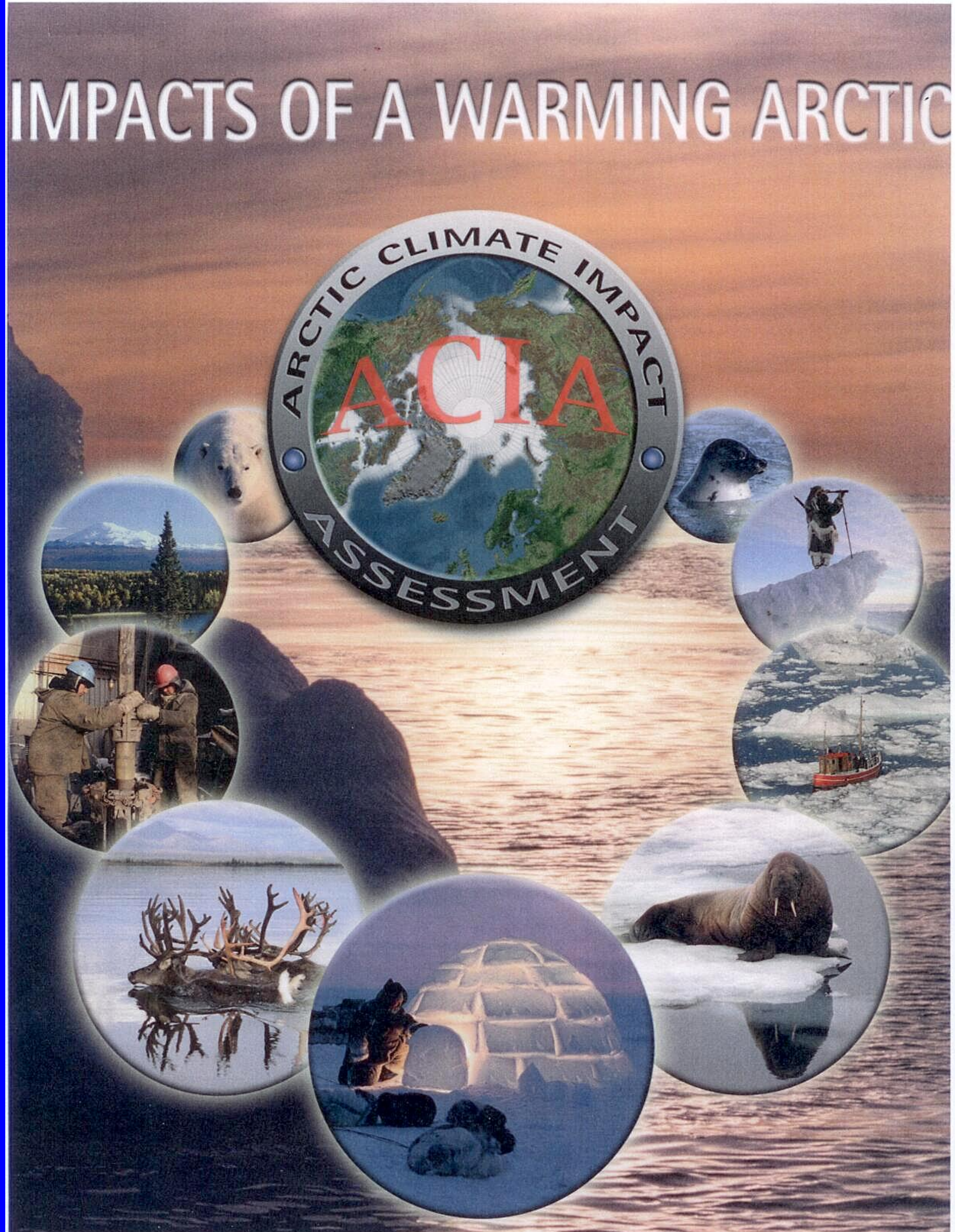
DESIGN IMPLICATIONS FOR EMBANKMENTS, DITCHES, CULVERTS, DRAINS, STREET HARDWARE AND PAVEMENTS WITH RESPECT TO HEAVY PRECIPITATION AND STORMWATER MANAGEMENT, PARTICULARLY IN URBAN AREAS WHERE PAVEMENTS MAKE UP A LARGE COMPONENT OF THE LAND SURFACE.

COASTAL ISSUES RELATED TO SEA LEVEL RISE

COASTAL AREAS OF ATLANTIC CANADA, QUÉBEC, SOUTHWESTERN BRITISH COLUMBIA AND NORTHWEST TERRITORIES

HIGHER MEAN SEA LEVELS, PARTICULARLY COUPLED WITH HIGH TIDES AND STORM SURGES, ARE MOST LIKELY TO INUNDATE AND/OR DAMAGE EMBANKMENTS, PAVEMENT STRUCTURES AND MUNICIPAL INFRASTRUCTURE UNDER ROADS (THE REPLACEMENT VALUE OF IMPACTED INFRASTRUCTURE HAS BEEN ESTIMATED TO BE IN THE HUNDREDS OF MILLION DOLLARS UNLESS APPROPRIATE ADAPTATION IS COMPLETED.

GOLDEN EARS BRIDGE AT M6 PIER, DECEMBER 2008


IMPACTS OF A WARMING ARCTIC
ARCTIC CLIMATE IMPACT ASSESSMENT
ACIA

FAR NORTHERN ISSUES RELATED TO CLIMATE WARMING

FAR NORTHERN CANADA IS WHERE THE MOST SIGNIFICANT WARMING IS EXPECTED AND THE PHYSICAL LANDSCAPE IS HIGHLY SENSITIVE TO ANY CLIMATE CHANGE. PERMAFROST (GROUND THAT REMAINS AT OR BELOW 0°C FOR AT LEAST TWO YEARS) UNDERLIES ALMOST HALF OF CANADA'S IMPORTANT STRUCTURAL SUPPORT FOR INFRASTRUCTURE SUCH AS ALL-SEASON ROAD AND AIRPORT PAVEMENTS.

DEGRADATION OF PERMAFROST AS A RESULT OF CLIMATE WARMING
(E.G. INCREASED DEPTH OF SEASONAL THAW LAYER, MELTING OF ICE IN THAW LAYER AND WARMING OF FROZEN ZONE, REDUCING ITS BEARING CAPACITY – PAVED ROADS AND RUNWAYS PARTICULARLY VULNERABLE AS THEY READILY ABSORB SOLAR ENERGY DUE TO LOW ALBEDOS COMPARED TO SNOW AND ICE – THE TYPICAL ALBEDO OF FRESH SNOW IS 0.75 TO 0.95, OF HMA IS 0.05 (FRESH) TO 0.17 (AGED) AND PCC 0.27 TO 0.17 (AGED).
SHORTENED ICE ROAD SEASONS BY SEVERAL WEEKS, UNLESS MORE INTENSIVE AND ADVANCED IR CONSTRUCTION AND MAINTENANCE (IRs CONSTRUCTED BY CLEARING AND DEVELOPING ROUTES ACROSS FROZEN GROUND, LAKES AND/OR RIVERS ARE IMPORTANT TO NORTHER TRANSPORTATION)
MORE ATTENTION TO THE SAFETY OF ROAD CONSTRUCTION AND MAINTENANCE STAFF WITH INCREASED FREEZE-THAW AND SLIPPERY CONDITIONS

THE PIARC TECHNICAL COMMITTEE C4.5 EARTHWORKS 2008 REPORT "ANTICIPATING THE IMPACT OF CLIMATE CHANGE ON ROAD EARTHWORKS" PROVIDES CONSIDERABLE TECHNICAL INFORMATION THAT SUPPLEMENTS AND EXTENDS THE TECHNOLOGY GIVEN ABOVE, INCLUDING QUÉBEC AS A REGIONAL SCENARIO EXAMPLE AND NORTH OF CANADA AND ALASKA PERMAFROST THAWING

CANADIAN ACTIVITIES TO ASSESS AND/OR ADDRESS THE CONSEQUENCES OF CLIMATE CHANGE ON ROAD PAVEMENTS

NATURAL RESOURCES CANADA www.adaptation.nrcan.gc.ca

- CLIMATE CHANGE IMPACTS AND ADAPTATION PROGRAM

ENVIRONMENT CANADA www.ec.gc.ca

- CLIMATE MODELLING AND ANALYSIS; CLIMATE MONITORING AND DATA ANALYSIS; COLD CLIMATE PROCESSES AND CRYOSPHERE; AND GREENHOUSE GASSES AND AEROSOLS

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE (IDRC) www.idrc.ca

- CLIMATE CHANGE AND ENVIRONMENTAL ECONOMIC PROGRAMS

INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)

- INTERNATIONAL AVIATION ACTION ON CLIMATE CHANGE

ONTARIO MINISTRY OF TRANSPORTATION (MTO) www.mto.gov.on.ca

- INCORPORATION OF ENVIRONMENTAL CONSIDERATIONS IN ALL OPERATIONS AND IMPROVED ENVIRONMENTAL STEWARDSHIP (GREENPAVE LEED)

PROVINCE OF QUÉBEC www.gouv.qc.ca

- PARTNERING TO TACKLE CLIMATE CHANGE AND CONSORTIUM ON REGIONAL CLIMATOLOGY AND ADAPTATION TO CLIMATE CHANGE (OURANOS) www.ouranos.ca

TORONTO AND REGION CONSERVATION AUTHORITY (TRCA) www.trca.on.ca

- PREPARING FOR THE IMPACTS OF CLIMATE CHANGE ON STORM WATER AND FLOOD PLANE MANAGEMENT

TRANSPORTATION ASSOCIATION OF CANADA www.tac.ca

- CLIMATE CHANGE TASK FORCE AND GREEN GUIDE FOR ROAD MAP TASK FORCE

FEDERATION OF CANADIAN MUNICIPALITIES www.gmf.fcm.ca

- SUPPORT OF MUNICIPAL INITIATIVES THAT IMPROVE AIR, WATER AND SOIL QUALITY AND PROTECT THE CLIMATE

CANADIAN ACTIVITIES (CONTINUED)

THE CLEAN AIR PARTNERSHIP (CAP) www.cleanairpartnership.org

PARTNERING, ESPECIALLY WITH MUNICIPAL GOVERNMENTS, ON CLEAN AIR, CLIMATE CHANGE MITIGATION AND ADAPTATION

PUBLIC INFRASTRUCTURE ENGINEERING VULNERABILITY COMMITTEE (PIEVC)

www.pievc.ca SYSTEMATICALLY EXAMINING INFRASTRUCTURE VULNERABILITY TO CLIMATE CHANGE FROM AN ENGINEERING PERSPECTIVE AND DEFINING ADAPTIVE CAPACITY INDICATORS

ONTARIO GOOD ROADS ASSOCIATION (OGRA) www.ogra.org

WORKSHOPS ON SNOW AND ICE CONTROL AND SALT MANAGEMENT

CANADIAN STANDARDS ASSOCIATION (CSA) www.csa.ca

EVALUATING THE CURRENT STATE OF KNOWLEDGE AMONGST PRACTISING INFRASTRUCTURE ENGINEERS AND THE ROLE OF STANDARDS IN ADAPTING TO THE IMPACTS OF CLIMATE CHANGE. CURRENT PUBLICATIONS:

- THE ROLE OF STANDARDS IN ADAPTING CANADA'S INFRASTRUCTURE TO THE IMPACTS OF CLIMATE CHANGE (2006)
- CLIMATE CHANGE AND INFRASTRUCTURE ENGINEERING: MOVING TOWARDS A NEW CURRICULUM (2007)
- TECHNICAL GUIDE: INFRASTRUCTURE IN PERMAFROST: A GUIDELINE FOR CLIMATE CHANGE ADAPTATION (2010)

LAVAL UNIVERSITY

NSERC INDUSTRIAL RESEARCH CHAIR ON HEAVY LOADS/WEATHER/PAVEMENT INTERACTION (i3C) http://i3c.gci.ulaval.ca/en/homepage

UNIVERSITY OF WATERLOO www.civil.uwaterloo.ca/cpatt

CENTRE FOR PAVEMENT AND TRANSPORTATION TECHNOLOGY (CPATT)

NORMAN MCLEOD CHAIR IN SUSTAINABLE PAVEMENTS

CANADIAN ACTIVITIES (CONTINUED)

UNIVERSITY OF CALGARY   www.ucalgary.ca

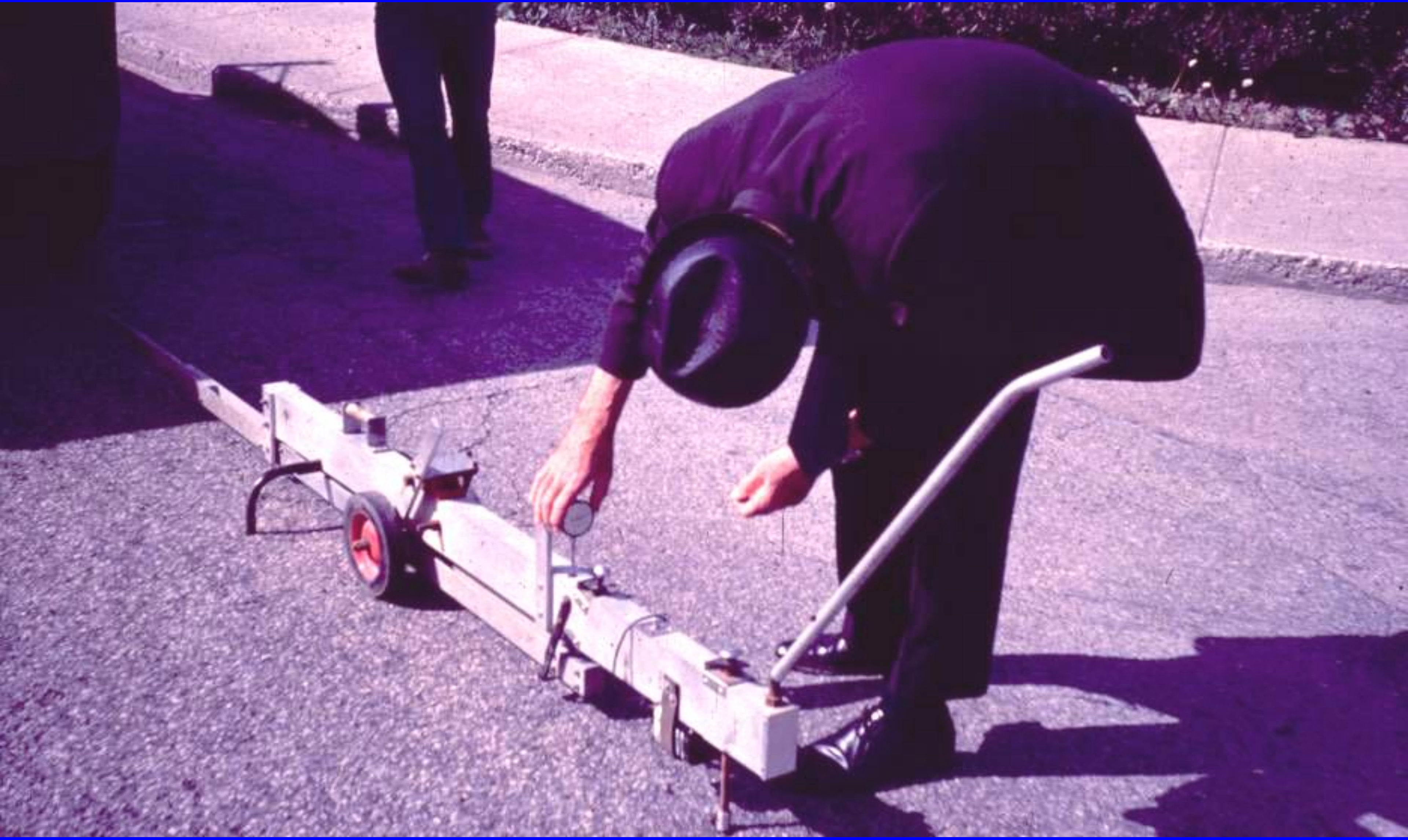
- NSERC/JOHN LAU HUSKY ENERGY INDUSTRIAL RESEARCH CHAIR IN BITUMINOUS MATERIALS

UNIVERSITY OF VICTORIA   www.climate.uvic.ca

- CLIMATE MODELLING LABORATORY
- CANADIAN INSTITUTE FOR CLIMATE STUDIES (CICS)   www.cics.uvic.ca
- PACIFIC CLIMATE IMPACTS CONSORTIUM (PCIC)   http://pacificclimate.org
  - COLLABORATION AMONG GOVERNMENT, ACADEME AND INDUSTRY TO REDUCE VULNERABILITY TO EXTREME WEATHER EVENTS, CLIMATE VARIABILITY AND THE THREAT OF GLOBAL CHANGE.

ONTARIO HOT MIX PRODUCERS ASSOCIATION   www.ohmpa.org

CEMENT ASSOCIATION OF CANADA   www.cement.ca



BENKELMEN BEAM (1980's)
THE LATE DR. NORMAN McLEOD, ORDER OF CANADA

PRIMARY CLIMATE CHANGE IMPACTS ON PAVEMENT STRUCTURES IN THE ARCTIC AND SUBARCTIC

ADAPTED FROM ACIA AND IPCC

THE THREE PRIMARY DETRIMENTAL, AND REALATIVELY COSTLY FOR ADAPTATION, IMPACTS OF THE OBSERVED AND PROJECTED RAPID AND RELATIVELY SEVERE ARCTIC CLIMATE WARMING TRENDS (RISING TEMPERATURES, INCREASING PRECIPITATION, THAWING PERMAFROST, DECLINING SNOW COVER, RISING RIVER FLOWS, DIMINISHING LAKE AND RIVER ICE, MELTING GLACIERS AND ICE SHEETS, RETREATING SUMMER SEA ICE, AND RISING SEA LEVELS) ON ROAD AND AIRPORT PAVEMENT STRUCTURES (INCLUDING ASSOCIATED EMBANKMENTS, CUTS AND FILLS, SLOPES, DRAINAGE SYSTEMS, AND BRIDGES) ARE, IN DECREASING ORDER OF ARCTIC AND SUBARCTIC EXTENT:

1. THAWING FROZEN GROUND – DEGRADATION OF PERMAFROST, INCREASING FREEZE THAW CYCLES, FROST HEAVING AND ACTIVE LAYER THICKNESSES AND EXTENTS, DECREASING THE LOAD BEARING CAPACITY, AND SOME POOR PREVIOUS ENGINEERING PRACTICES ON PERMAFROST.

2. DELAYED ICE FORMATION AND REDUCED ICE THICKNESS OF WINTER ICE ROADS AND BRIDGES AND A REDUCED FROZEN TUNDRA.

3. INUNDATION AND DAMAGE (EROSION, FOR INSTANCE) OF PAVEMENT STRUCTURES DUE TO RISING SEA LEVELS.

McGraw-Hill

COLD REGIONS PAVEMENT ENGINEERING

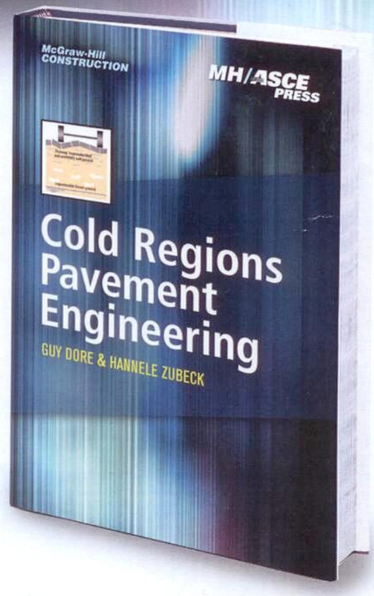
GUY DORÉ, LAVAL UNIVERSITY, QUEBEC • HANNELE K. ZUBECK, UNIVERSITY OF ALASKA ANCHORAGE

Pavements in cold regions—such as Minnesota and Alaska in the United States, as well as other countries such as Canada, Finland, and Russia—are subject to distress by climatic and environmental factors. It is critical that engineers know the factors contributing to overall performance of roads in cold regions, as well as how to design and maintain these roads considering such conditions. This book prepares civil engineers to make the right decisions in areas where freezing temperatures, unstable soils, snow and ice, sparse population, and often limited funds dictate the design and maintenance of pavement structures.

This unique book, combining the latest research as well as proven techniques from the United States, Canada, and Northern Europe, will be the first complete reference for all pavement projects in cold regions.

Guy Doré, Ph.D., ing., is a professor in the civil engineering department at Laval University in Quebec, Canada.

Hannele K. Zubeck, Ph.D., P.E., is a professor in Civil Engineering and chair of the Arctic Engineering Program at the University of Alaska Anchorage.



CONTENTS

Guy Doré, Laval University, Quebec

Hannele K. Zubeck, University of Alaska Anchorage

Publication date: 2008

Pages: 432

Price: $175.00 McGraw-Hill
$131.25 ASCE Members

Trim size: 7.5 x 9.5

Binding: Hardcover

Bulk buy: 250 copies

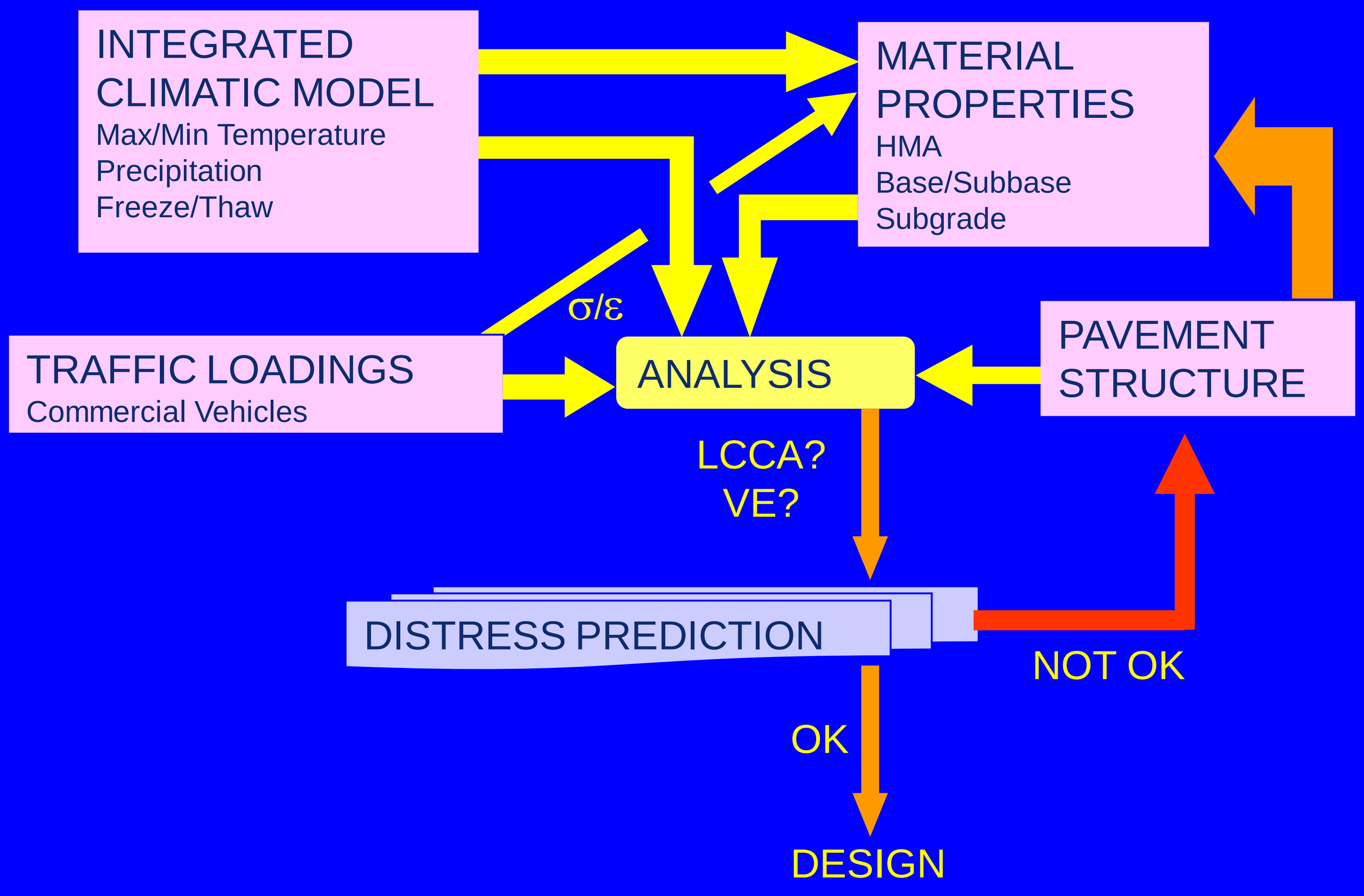
NEW ADAPTATION TECHNOLOGIES FOR PAVEMENT STRUCTURES ON PERMAFROST

ADAPTED FROM DORÉ AND ZUBECK

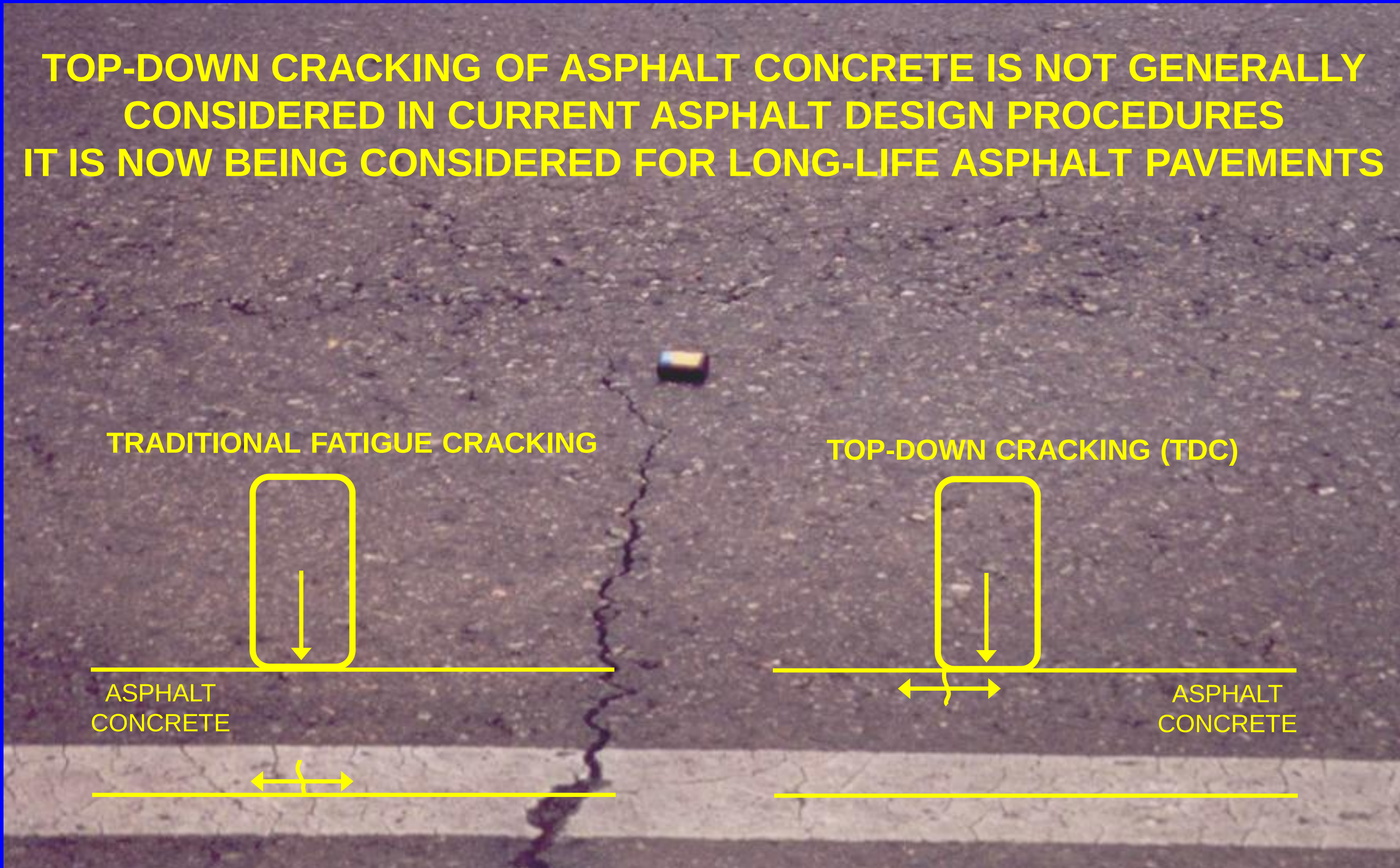
1. USE OF ARTIFICIAL COOLING TO ENSURE THAT SUBGRADES AND EMBANKMENTS REMAIN FROZEN
2. USE OF THERMOSYPHONS TO ENHANCE WINTER HEAT EXTRACTION FROM THE GROUND
3. USE OF INSULATION WITHIN EMBANKMENTS (FILLS) TO MINIMIZE THERMAL DISTURBANCE
4. USE OF OPEN-GRADED ROCK EMBANKMENT MATERIALS TO MOBILIZE EFFECTIVE HEAT TRANSFER WITHIN EMBANKMENTS
5. EXCAVATION OF FROZEN ICE-RICH MATERIAL AND REPLACEMENT WITH THAW-STABLE MATERIAL;
6. INTENTIONAL THAWING OF PERMAFROST, WITH POSTPONEMENT OF CONSTRUCTION UNTIL AFTER THE GROUND HAS SETTLED
7. USE OF LIGHT-COLOURED COATINGS, REFLECTIVE SURFACE COATINGS AND/OR LIGHT COLOURED AGGREGATES (HIGH ALBEDO) ON ASPHALT CONCRETE AND CHIP-SEAL SURFACES (LOW ALBEDO) TO DECREASE PAVEMENT SURFACE TEMPERATURES AND REDUCE POTENTIAL PERMAFROST THAWING
8. USE OF ENHANCED PAVEMENT MAINTENANCE MONITORING TO DETECT POTENTIAL PROBLEM AREAS SO THAT THEY CAN BE PROPERLY REPAIRED BEFORE THEY INTERFERE WITH ROAD USE (GROUND PENETRATING RADAR USE, FOR INSTANCE)

NORTH EAST STONEY TRAIL
WINTER CONSTRUCTION WITH GROUND HEATING
JANUARY 2009

FLOWCHART FOR DESIGN OF ASPHALT PAVEMENTS

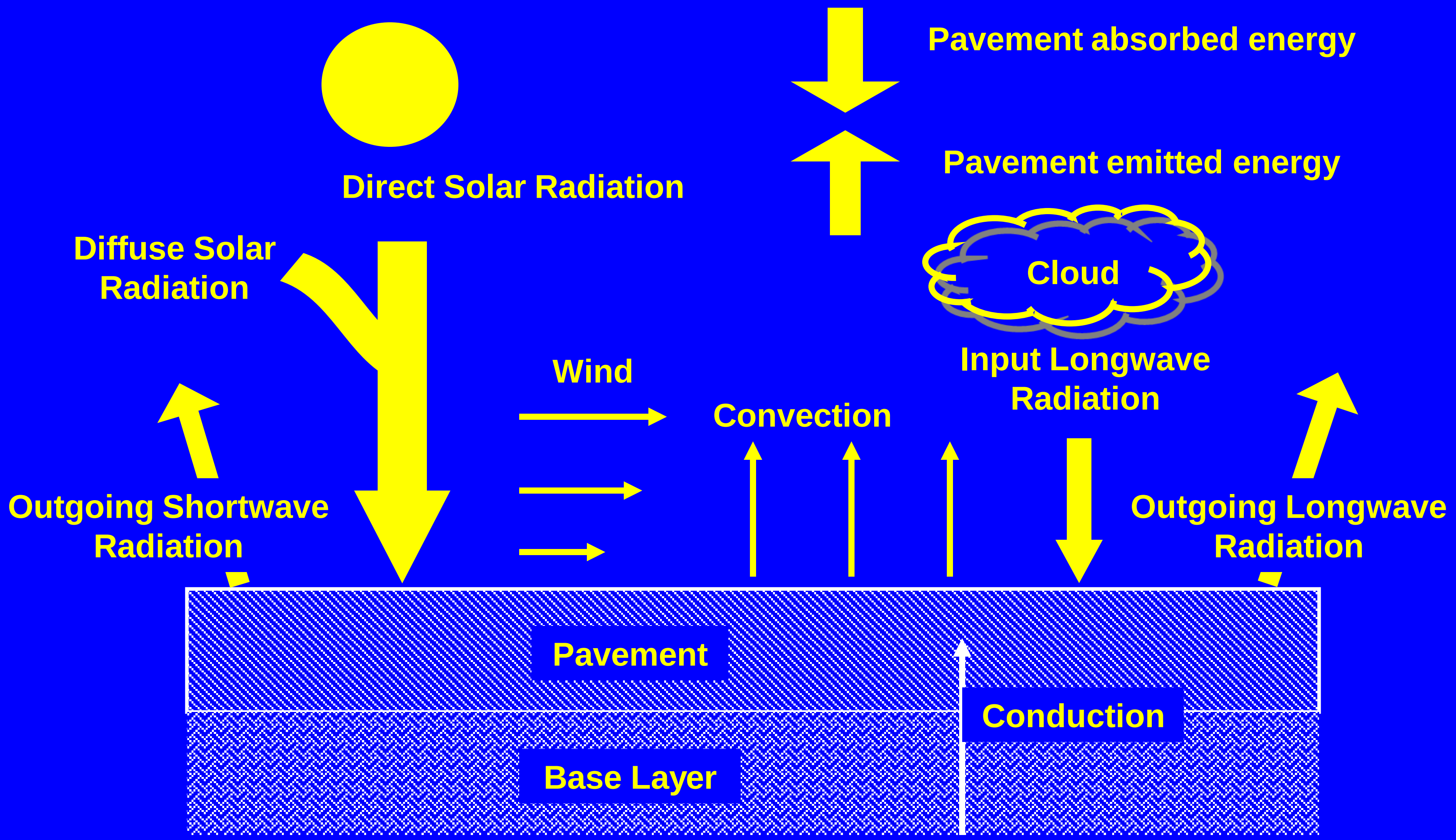


TOP-DOWN CRACKING OF ASPHALT CONCRETE IS NOT GENERALLY CONSIDERED IN CURRENT ASPHALT DESIGN PROCEDURES
IT IS NOW BEING CONSIDERED FOR LONG-LIFE ASPHALT PAVEMENTS



CRACKING OF RELATIVELY NEW ASPHALT PAVEMENT HOTHOT, INNER MONGOLIA
TRANSVERSE THERMAL CRACK WITH TOP DOWN CRACKING (TDC) IN WHEELPATH

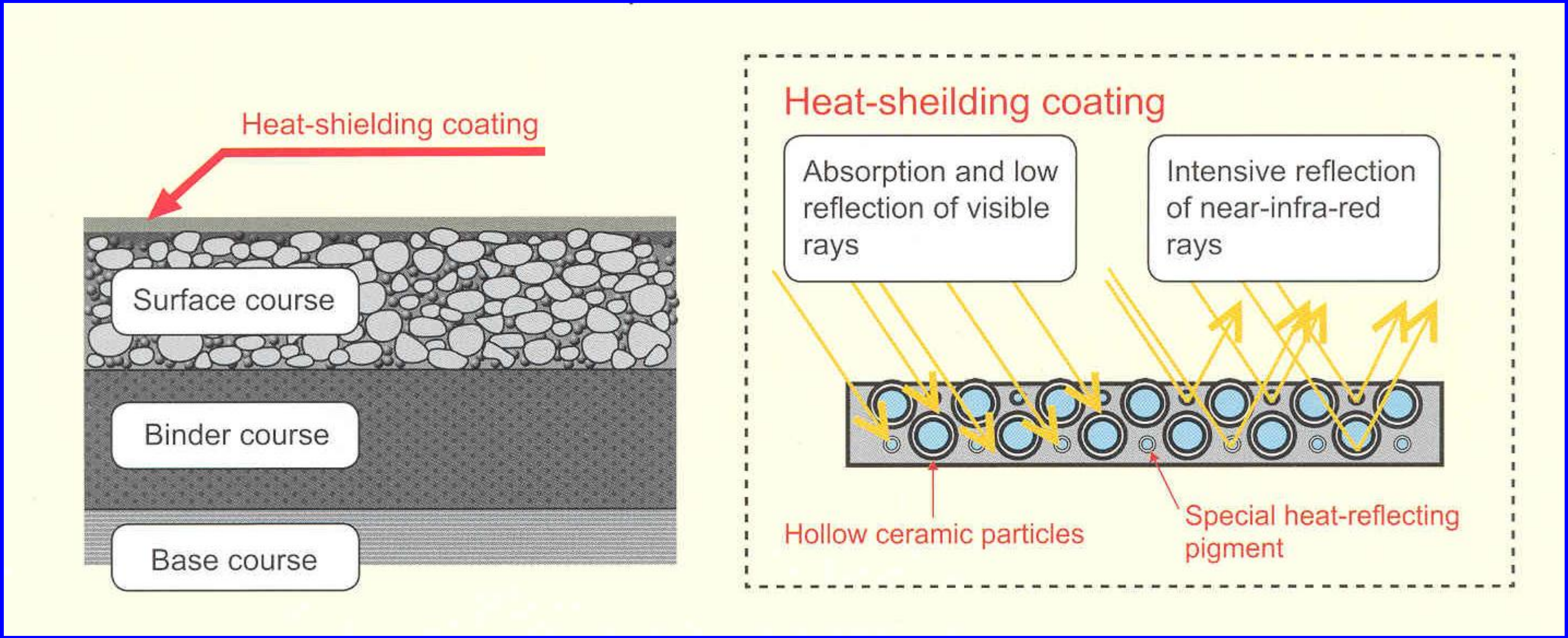
THE EFFECT OF ENVIRONMENTAL FACTORS ON ASPHALT PAVEMENT TEMPERATURE



SUN, JIA AND QIN, ISAP 2006

CURRENT JAPANESE RESEARCH ON HEAT-SHIELD ASPHALT PAVEMENTS

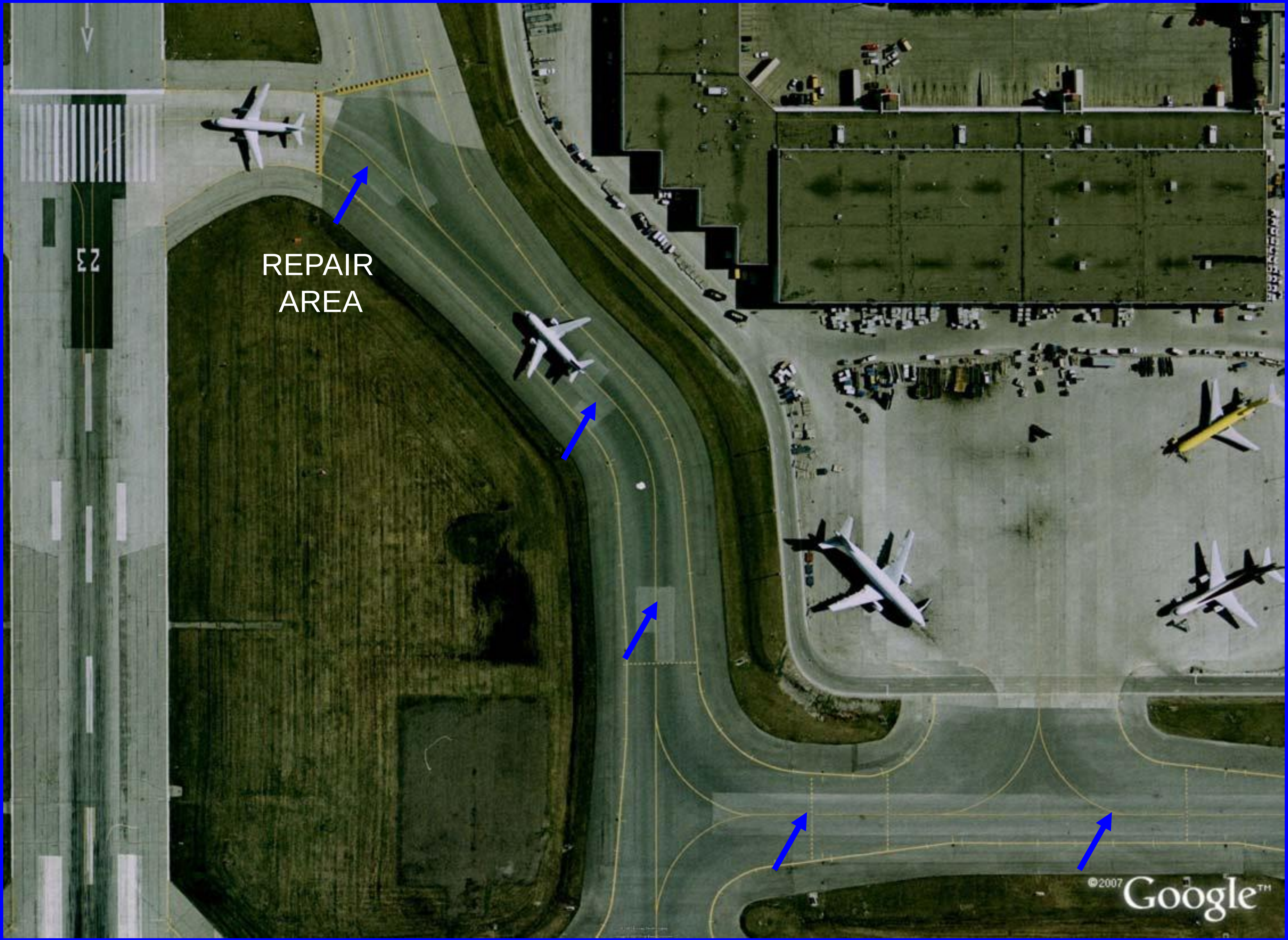
COMPARED TO ORDINARY ASPHALT PAVEMENTS, HEAT-SHIELD PAVEMENTS REDUCE THE SURFACE TEMPERATURE BY MORE THAN 15 C, AND ARE EXPECTED TO IMPROVE THE THERMAL ENVIRONMENT IN URBAN AREAS



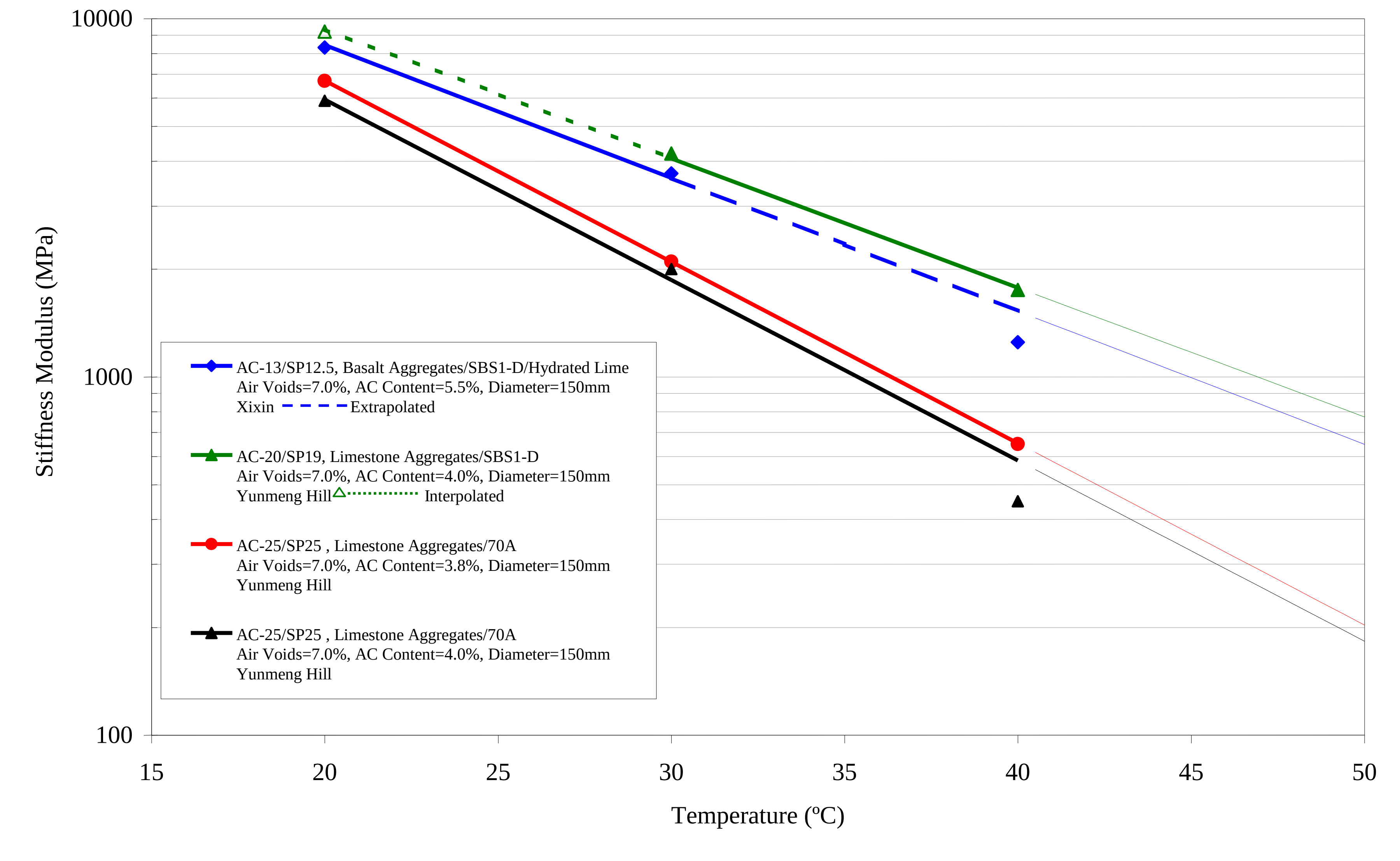
PWRI, PIARC SEPTEMBER 2007

HEAT-SHIELDING COATING MATERIALS (SPECIAL PAINT) THAT PRIMARILY REFLECT INFRARED RAYS ARE INCORPORATED INTO THE PAVEMENT SURFACE. INTENSIVE REFLECTION OF INFRARED RAYS REDUCES ACCUMULATED HEAT IN THE PAVEMENT.

COMPOSITE PAVEMENT 2002 REPAIR AREAS AT PEARSON AIRPORT – 2006



RESILIENT MODULUS OF ASPHALT CONCRETE LABORATORY (SUPERPAVE-GYRATORY COMPACTOR) PREPARED SAMPLES BASED ON MIX DESIGNS



HEDL EXPRESSWAY CHINA

PAVEMENT TEMPERATURE VARIATION WITH DEPTH WITHOUT HYDRATED LIME SURFACE COATING

Depth (cm)	1	2	3	4	5
	< 25ºC	25º C to 35ºC	35º C to 40ºC	40º C to 45ºC	> 45ºC
0 cm, ºC	22.5	32.5	40.0	45.0	47.5
2 cm, ºC	20.0	30.0	37.5	42.5	45.0
7 cm, ºC	20.0	23.0	30.5	35.5	38.0
15 cm, ºC	15.0	17.0	24.5	29.5	32.0
25 cm, ºC	15.0	15.0	22.5	27.5	30.0

PAVEMENT TEMPERATURE VARIATION WITH DEPTH WITH HYDRATED LIME SURFACE COATING

Depth (cm)	1	2	3	4	5
	< 25ºC	25º C to 35ºC	35º C to 40ºC	40º C to 45ºC	> 45ºC
0 cm, ºC	21.5	30.5	37.0	41.0	42.5
2 cm, ºC	19.0	28.0	34.5	38.5	40.0
7 cm, ºC	20.0	23.0	30.5	32.5	35.0
15 cm, ºC	15.0	17.0	24.5	28.5	30.0
25 cm, ºC	15.0	15.0	22.5	26.5	29.0

ASPHALT CONCRETE RESILIENT MODULUS WITH DEPTH WITHOUT HYDRATED LIME

Layer	Season	1		2		3		4		5	
		< 25ºC		25º C to 35ºC		35º C to 40ºC		40º C to 45ºC		> 45ºC	
		20.0		30.0		37.5		42.5		45.0	
	Depth	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi
AC-13/SP12.5 SBS1-D	2 cm	8,440	1,224,118	3,590	520,685	1,890	274,121	1,230	178,396	1,000	145,038
AC-20/SP19 SBS1-D	7 cm	9,340	1,354,652	7,280	1,055,874	3,910	567,097	2,580	374,197	2,100	304,579
AC-25/SP25 70A	15 cm	12,040	1,746,254	9,530	1,382,209	3,980	577,250	2,220	321,984	1,660	240,763
AC-25/SP25 70A	25 cm	10,630	1,541,751	10,630	1,541,751	4,450	645,418	2,490	361,144	1,870	271,220

ASPHALT CONCRETE RESILIENT MODULUS WITH DEPTH WITH HYDRATED LIME

Layer	Season	1		2		3		4		5	
		< 25ºC		25º C to 35ºC		35º C to 40ºC		40º C to 45ºC		> 45ºC	
		19.0		28.0		34.5		38.5		40.0	
	Depth	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi
AC-13/SP12.5 SBS1-D	2 cm	9,190	1,332,896	4,260	617,861	2,440	353,892	1,740	252,366	1,530	221,908
AC-20/SP19 SBS1-D	7 cm	9,340	1,354,652	7,280	1,055,874	3,910	567,097	3,310	480,075	2,690	390,151
AC-25/SP25 70A	15 cm	12,040	1,746,254	9,530	1,382,209	3,980	577,250	2,490	361,144	2,090	303,129
AC-25/SP25 70A	25 cm	10,630	1,541,751	10,630	1,541,751	4,450	645,418	2,800	406,106	2,090	303,129

HEDL EXPRESSWAY CHINA

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METAPETROLEUM, COLOMBIA, JANUARY 2010

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