UNIVERSITY OF PISA

DEPARTMENT OF CIVIL ENGINEERING

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECTS AND FWD ANALYSIS

Alessandro Marradi
a.marradi@ing.unipi.it

OVERVIEW

1. MAIN GOALS OF DEFLECTION MEASUREMENTS
2. CHARACTERISTICS AND CAPABILITY OF COLD RECYCLING PROCESS
3. SOME ITALIAN CASE HISTORIES: FREEWAY FLORENCE-PISA, CIAMPINO (ROME) INTERNATIONAL AIRPORT, ELBA ISLAND AIRPORT
4. PROBLEMS RELATED TO BACKCALCULATION ANALYSIS IN PAVEMENTS CONTAINING COLD RECYCLED LAYERS
5. POTENTIAL STRATEGIES AND SOLUTIONS

DEFLECTION MEASUREMENTS

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

DEFLECTION MEASUREMENTS (overview)

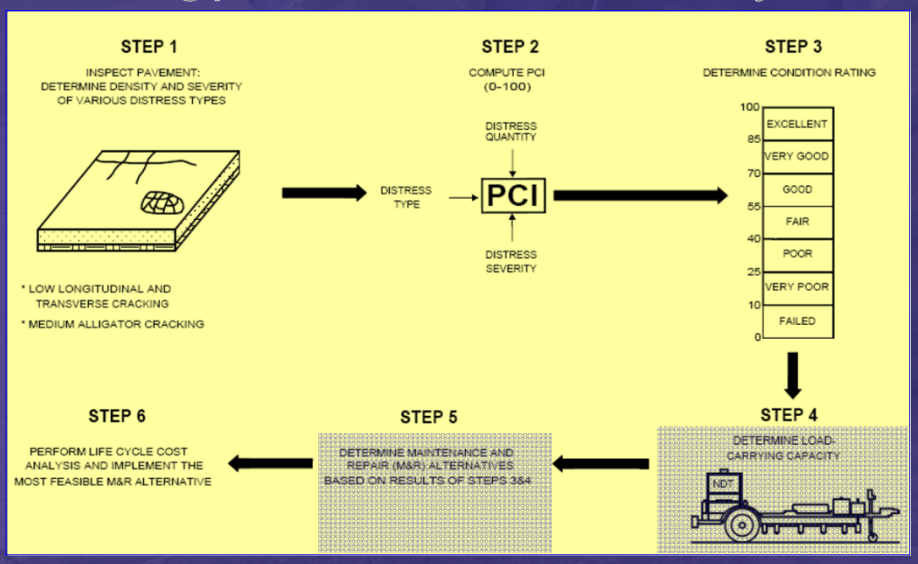
1. WHY?
 - What is actually wrong in the exixting pavement?
 - Is the target bearing capacity of the rehabilitated pavement respected?
 - Routine controls for pavement management (PMS) – residual life

2. WHEN?
 - curing time (short term / long term stiffness), temperature sensitivity, traffic load effects, enviromental effects

3. WHERE?
 - wheelpath, loaded area (keel section), unloaded area

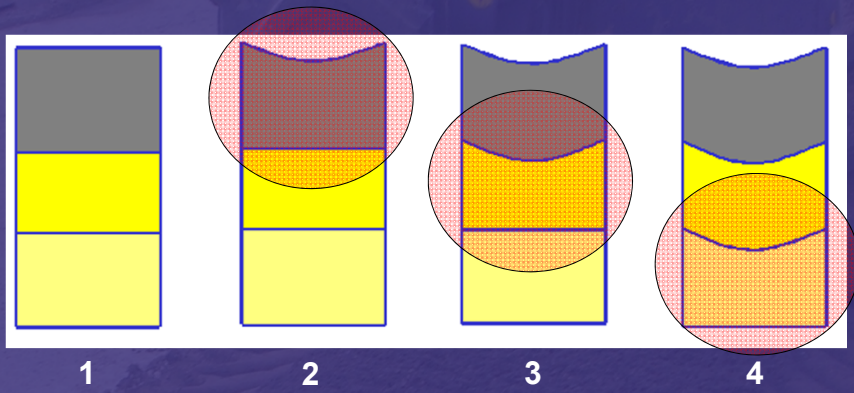
Depending to the answer to these questions we can have different practice (different instruments, different elaboration procedures)

Assessing pavement conditions – not only visual



DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

Assessing pavement conditions – not only visual



Assessing pavement conditions
Homogeneous Sections

Based on:

STRUCTURAL & FUNCTIONAL CONTITIONS

A sub-section is a part of the network that has the same uniform pavement conditions (bearing capacity, residual life, roughness, etc.). When testing is performed at project level, sufficient measurements need to be performed to enable a network branch to be divided into homogeneous subsections.

PAVEMENT STRUCTURE

A sub-section is a part of the branch that has the same uniform pavement structure.

TRAFFIC

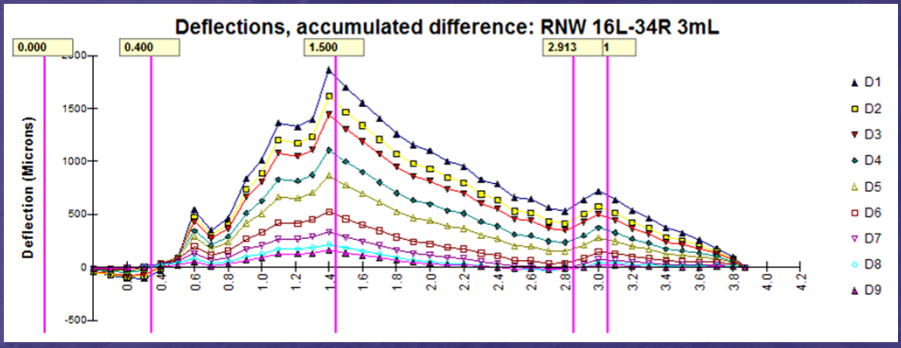
A sub-section is a part of the branch that has the same uniform traffic level (aircraft type, number of movements).

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

Assessing pavement conditions
Homogeneous Sections

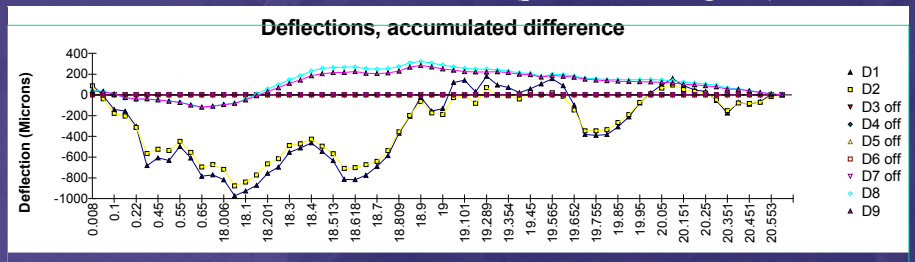
Based on:

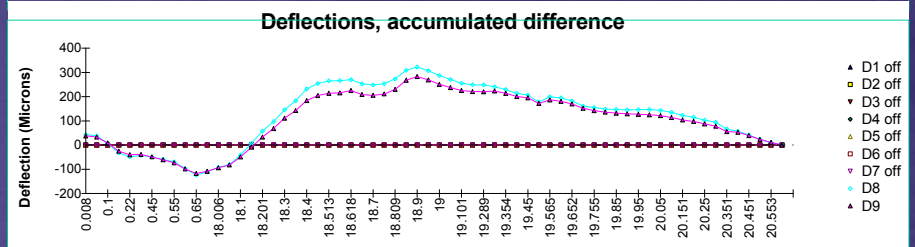
STRUCTURAL CONTITIONS (general)



Based on:

STRUCTURAL CONTITIONS (particular – subgrade)





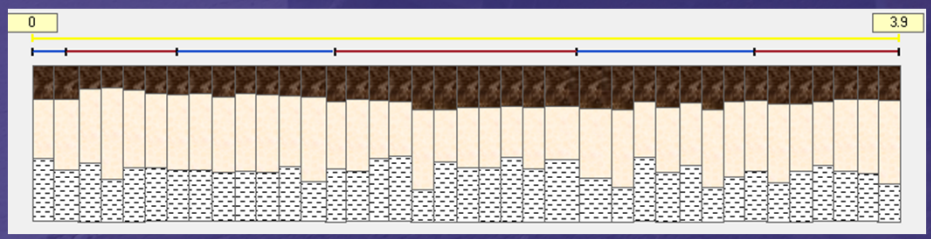
DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

Assessing pavement conditions
Homogeneous Sections

Based on:

PAVEMENT STRUCTURE

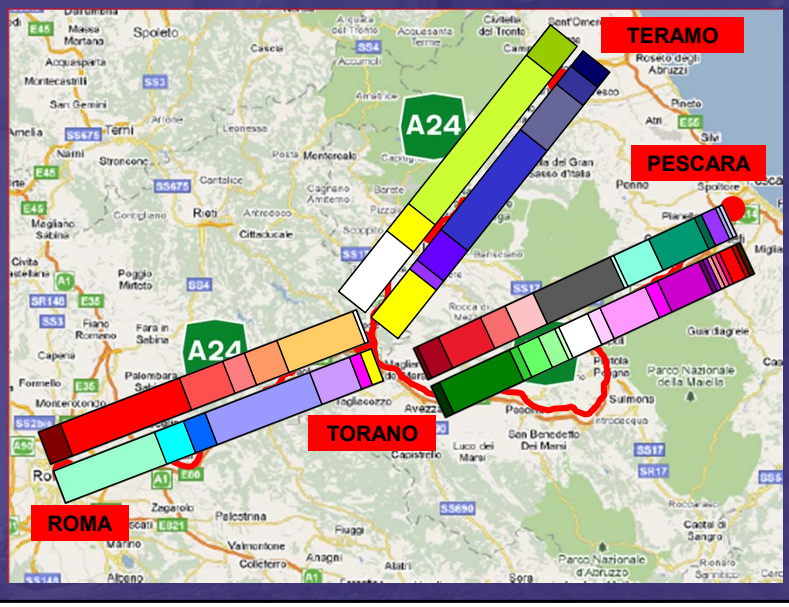
A sub-section is a part of the branch that has the same uniform pavement structure.



Assessing pavement conditions
Homogeneous Sections

Centre deflection	
Layer thicknesses	
Subgrade	
Traffic volumes	
Final division (4 subsections)	

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi



DEFLECTION MEASUREMENT

Why?

ASSES LAYERS STIFFNESS FOR *QC* ACTIVITIES

LAYER ELASTIC MODULI

GENERALLY THE VALUE OF ELASTIC MODULUS IS REQUIRED FOR EACH LAYERS USED IN PAVEMENT DESIGN AND CONSTRUCTION PROCEDURE.

MODULI ESTIMATED WITH FWD DEFLECTION MEASUREMENT HAVE TO COMPLY THE ONES ASSUMED DURING DESIGN PROCESS.

ESTIMATE PAVEMENT RESIDUAL LIFE IN PMS STRATEGY

IDENTIFY THE CRITICAL LAYER AND FIND THE BEST MAINTENANCE ALTERNATIVE

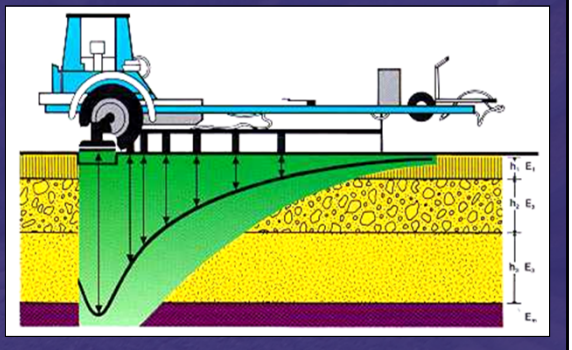
ELMOD: *EVALUATION LAYER MODULI OVERLAY DESIGN*

WE NEED TO HAVE SPECIFIC TRAFFIC DEMAGE MODEL FOR EACH LAYER (FATIGUE LAW)

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

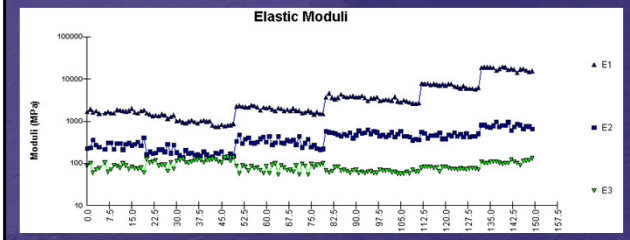
ASSES LAYERS STIFFNESS FOR *QC* ACTIVITIES

DURING CONSTRUCTION (DIRECTLY ON COLD RECYCLED LAYERS)
LWD (*Light Weight Deflectometer) and FWD* (*Falling Weight Deflectometer*)



ASSES LAYERS STIFFNESS FOR QC ACTIVITIES

FOR ROAD AND AIRFIELD (END OF CONSTRUCTION AND DURING SERVICE LIFE)→FWD *FALLING WEIGHT DEFLECTOMETER*→*BACK-CALCULATION OF ELASTIC MODULI*



Example:
Results of back-calculation of elastic moduli process for the following structure.
E1 = Asphalt layers moduli
E2 = Subbase layer moduli
E3 = Subgrade moduli

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

ESTIMATE PAVEMENT RESIDUAL LIFE

Load
Deflections
Layer thicknesses

Backcalculation of E-moduli

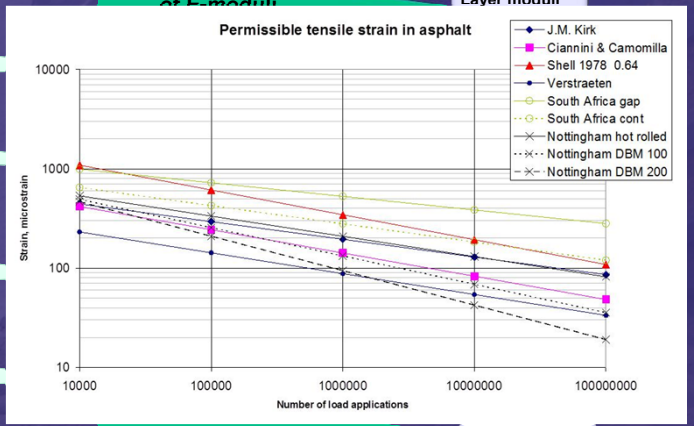
Layer moduli

Temperatures
Seasonal parameters

Design load

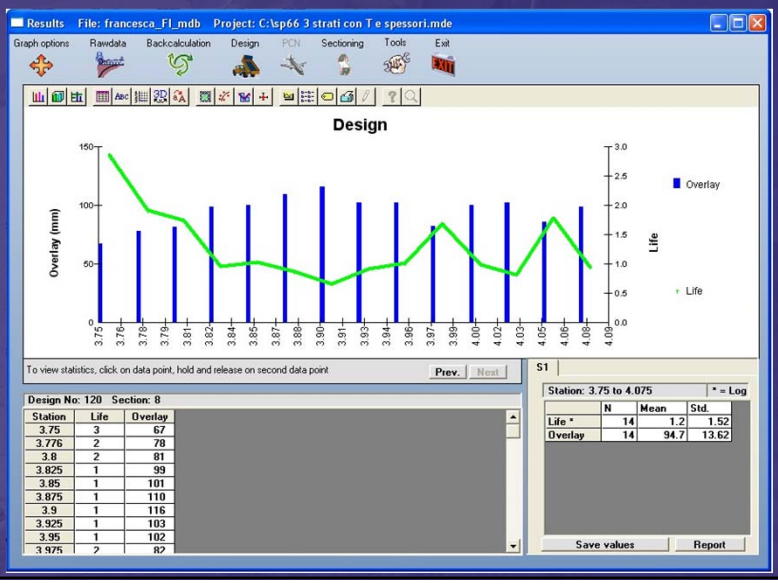
Traffic
Deterioration models

Design period
Design material



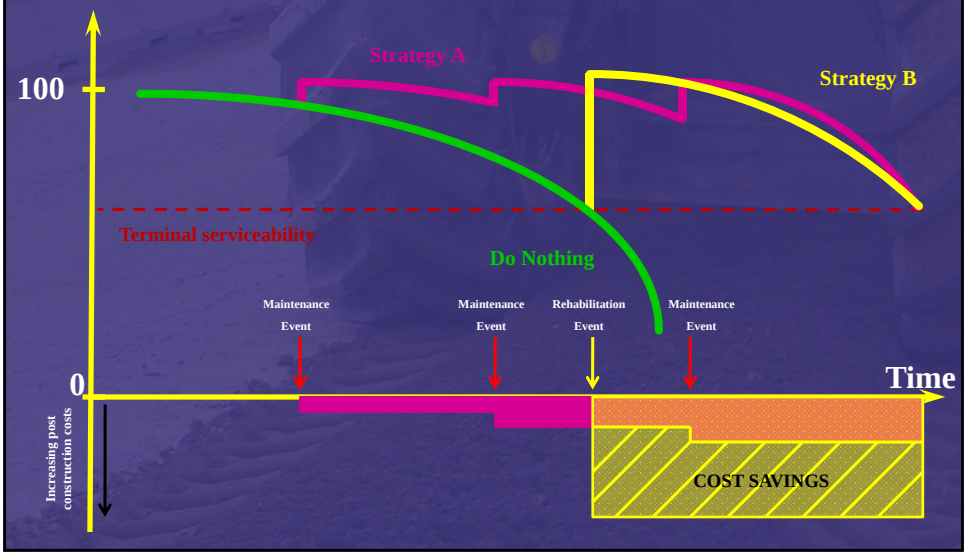
Point by point design

RESULTS OF RESIDUAL LIFE E VALUATION

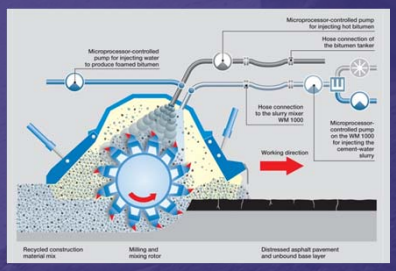


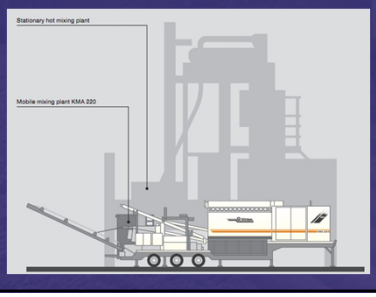
DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

PREVENTIVE MAINTENANCE – REACTIVE MAINTENANCE



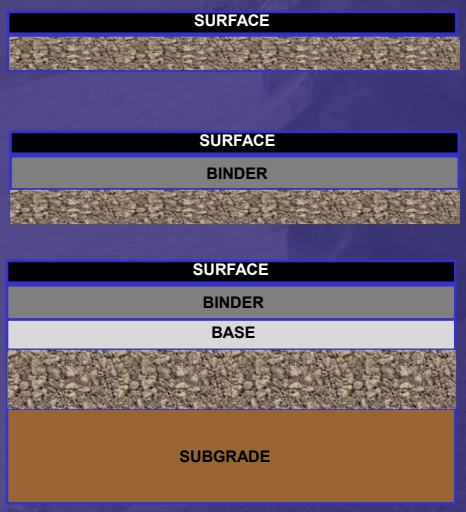
COLD RECYCLED LAYERS
WHAT WE ARE DEALING WITH?





DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

COLD RECYCLED LAYERS - TREND



BINDER STABILIZED LAYER WITH FOAMED BITUMEN

BASE STABILIZED LAYER WITH FOAMED BITUMEN

SUBBASE STABILIZED LAYER WITH FOAMED BITUMEN

DIFFICULTIES IN MIX PRODUCTION

IMPORTANCE IN THE PAVEMENT STRUCTURE

REMARKS

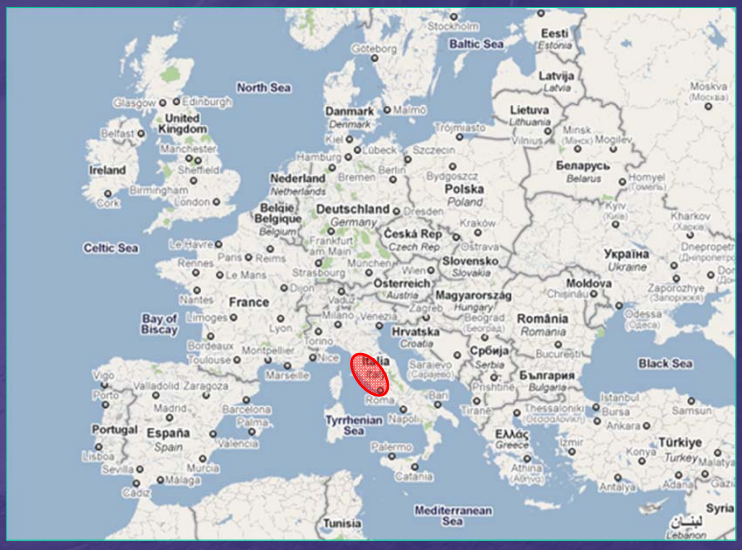
EVOLUTION OF TECHNOLOGY AND THE INCREASINGLY EXPERIENCE IN PRODUCTION AND APPLICATION OF RECYCLED MIXES ENCOURAGED CONTRACTORS TO USE THESE MIXES CLOSER AND CLOSER TO THE PAVEMENT SURFACE LAYER MAXIMIZING ECONOMIC AND ENVIROMENT BENEFITS.

STARTING FROM SUBBASE THE TARGET APPLICATIONS OF COLD RECYCLED MIXTURES NOW INCLUDE ALSO BASE AND BINDER LAYERS (AS A FUNCTION OF ROAD TYPE AND TRAFFIC CLASS)

THIS KIND OF EVOLUTION MAKE NOT NEGLIGEABLE PROBLEMS RELATED TO CONTROLS RELATED TO WORK SUPERVISION, IN TERM OF UNCOMMON BEHAVIOR OF PAVEMENT STRUCTURE. ALL THIS ISSUES ARE REFLECT ON PROBLEMS RELATED TO BACK-CALCULATION OF THIN LAYERS OVER BITUMEN STABILIZED MATERIALS.

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

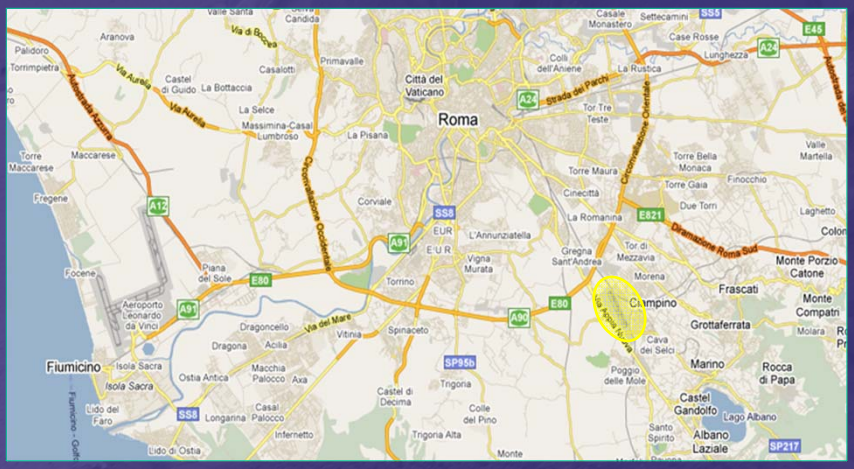
CASE HISOTORIES



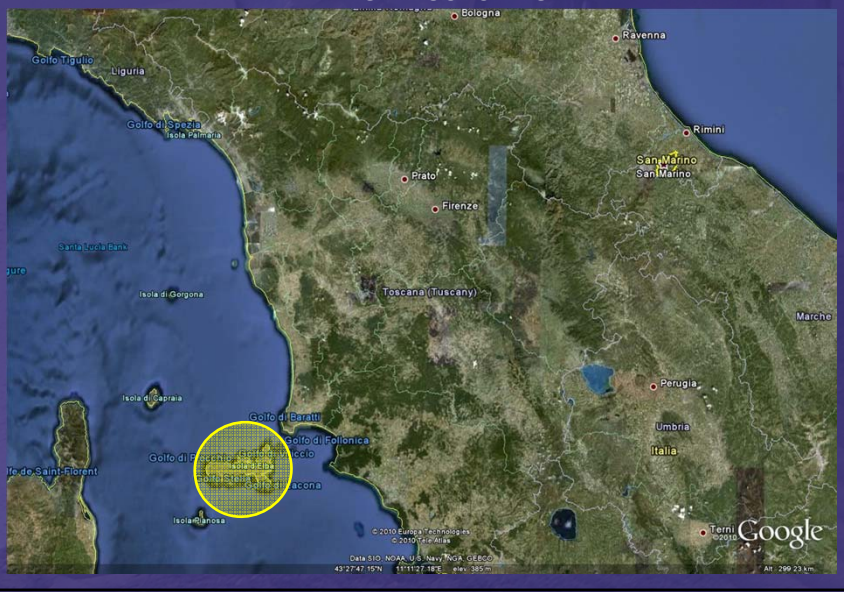
CASE HISOTORIES

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

CASE HISOTORIES



CASE HISOTORIES



DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

COLD RECYCLING

IN SITU RECYCLING
WIRTGEN WR 200

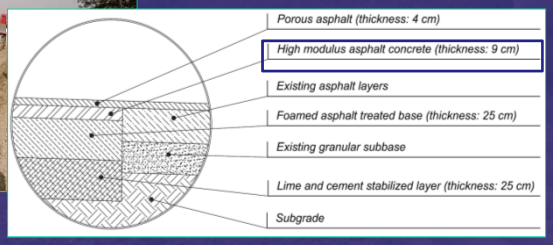
Cold recycling with WR - freeway Fl.Pl.Ll.

Cold recycling with KMA - Taxiway Alfa, Ciampino Airport

IN PLANT RECYCLING
KMA 220

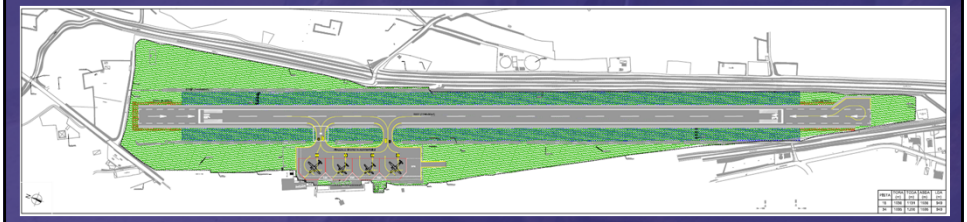
FREEWAY FLORENCE-PISA-LIVORNO

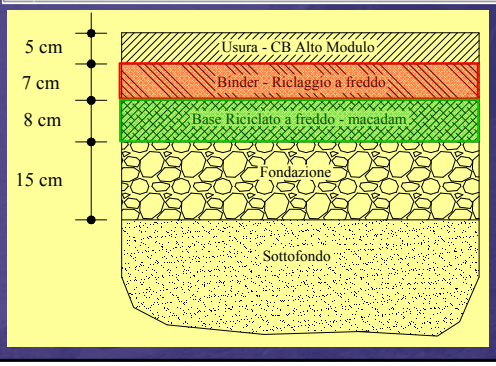
Defined by the Italian National Autonomous Company for Roads (ANAS) "Road of Great Communication", FI-PI-LI freeway plays a strategic role as part of Tuscany (Italy), connecting Florence (FI), Pisa (PI) and Livorno (LI).



DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

ELBA ISLAND AIRPORT (LIRJ-EBA)





Wearing course High Modulus WAM

Cold recycled Binder course

Cold recycled Base course

Lime stabilized existing subbase

CIA International Airport (Rome)

In plant cold recycling: the Ciampino Airport

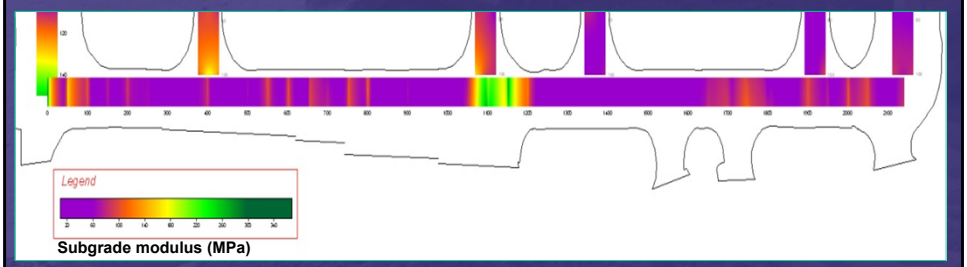
Rome Ciampino "Giovan Battista Pastine" Airport **is an integral part of the Rome airport system. After decades of stagnation in scheduled traffic, low-cost companies have boosted Ciampino, that is now one of the busiest and fastest growing airports in Italy. Traffic has grown so much that noise complaints forced the Italian Ministry of Transport to limit the number of daily flights.**

Ciampino Airports operate with *a single runway (15-33) 2200 m length with a single Taxiway (Alfa) parallel to the runway*

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

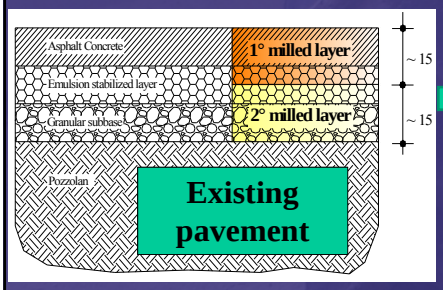
CIA International Airport (Rome)

Results of pavement evaluation tests undertaken in 2008 using Falling Weight Deflectometer evidenced urgent needs for structural rehabilitation primarily due to the very low bearing capacity of the subgrade not yet able to support the increased amount of traffic



Subgrade modulus (MPa)

CIA International Airport (Rome)

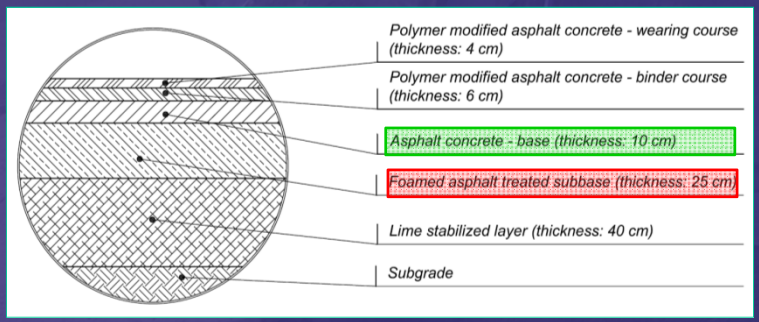


A mobile impact crusher was used to break down the oversized RAP particles so that *100% of RAP could be utilized*

The *Wirtgen KMA 220* cold mixing plant was used to obtain the designed mixture (3.0% foamed bitumen, 2.0% cement, 5.0% water), previously defined by a detailed laboratory test program

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

CIA International Airport (Rome)



As this was <u>the first application in Italy of foam stabilization for airport</u> pavements a specific <u>*trial section*</u> was constructed in the area with less traffic in order to verify the on site performance of the solutions adopted.

For the trial section an accurate test plan was prepared including LWD and DCP tests as well as FWD tests at different times after the completion of the pavement.

CIA International Airport (Rome)

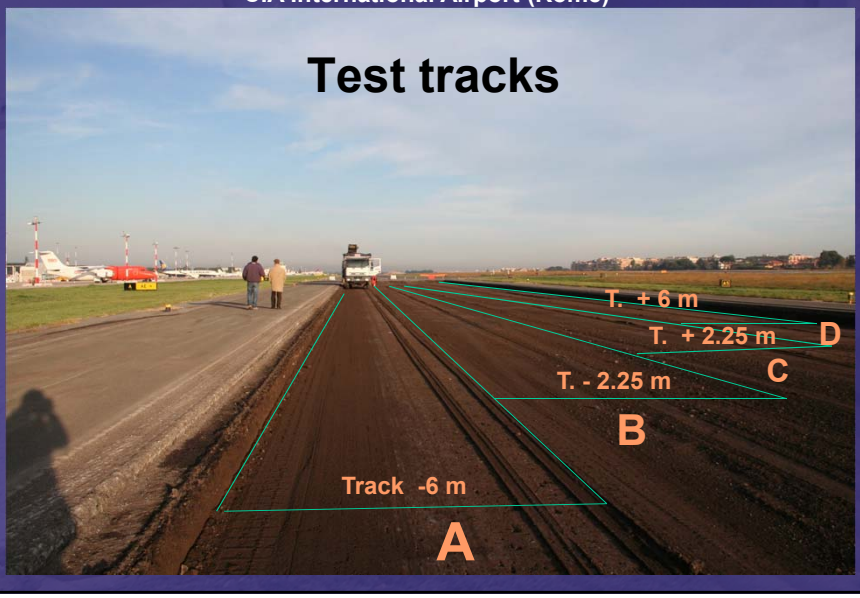
DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

CIA International Airport (Rome)

CIA International Airport (Rome)

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

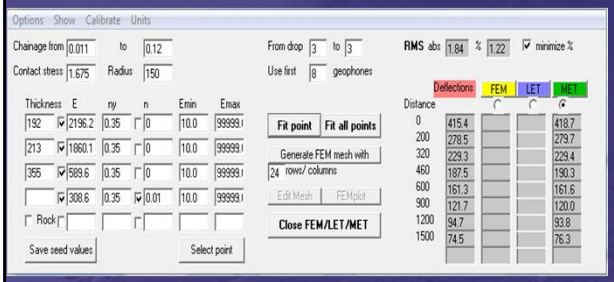
CIA International Airport (Rome)

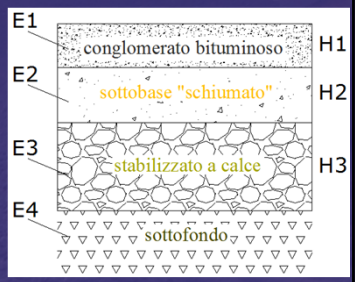


CIA International Airport (Rome)

Elaboration of deflection data - backcalculation

Equivalent elastic moduli were calculated using Dynatest Elmod 6 using a 4 layers model, repating tests at different period





DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

CIA International Airport (Rome)

03 Dec. 2009

19 Jan. 2010

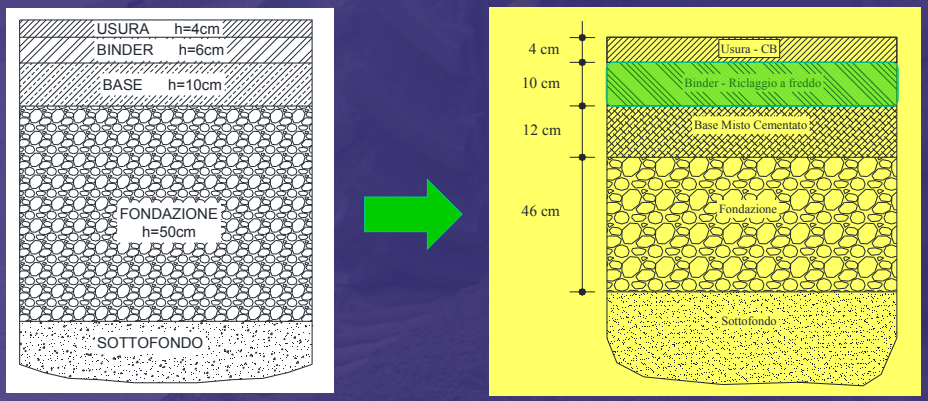
02 March 2010

27 Aug. 2010

	03/12/2009	19/01/2010	02/03/2010	27/08/2010
Conglomerato bituminoso	*4619*	*6727*	*5897*	*7700*
Sottobase riciclata a freddo	*1713*	*2306*	*2574*	*3670*
Sottofondo stabilizzato a calce	*383*	*339*	*412*	*512*
Sottofondo	*157*	*186*	*192*	*240*

PISA PROVINCE TEST Section (2km)

(cold recycled layer will start to be placed tomorrow)



DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

COLD RECYCLING

Bitumen stabilized materials have a "not-standard" behavior

USE OF RAP

- RAP content in the mix: 100% or x%? Depend on the structural function assigned to the recycled layer.
- Temperature dependance.
- RAP pre-treatment is requested: crashing, selection, stockpiling, etc…

CURING TIME → Initial increasing of stiffness due to aging and traffic.

TRAFFIC DAMAGE → Decreasing of modulus under cumulative loads.

" …Non-continuously bound materials, which comprise bitumen stabilised materials (BSMs) with either foamed bitumen or emulsified bitumen as binders, behave like granular materials with retained inter-particle friction but increased cohesion, and stiffness…."

WIRTGEN COLD RECYCLING MANUAL 2010

PROBLEMS RELATED TO BACKCALCULATION OF DEFLECTION DATA
(general)

1. ABILITY TO IDENTIFY WITH GROUND PENETRATING RADAR THIN LAYERS OVER FOAM STABILIZED BASE LAYERS

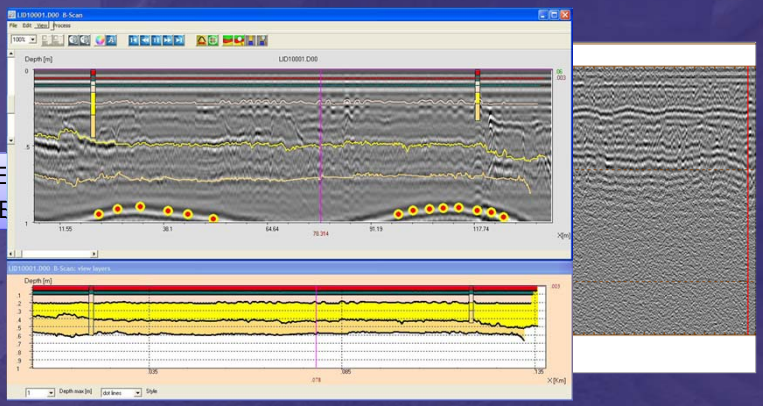
2. RESPECT … MODULI SHOULD DEC…

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

1. ABILITY TO IDENTIFY WITH GROUND PENETRATING RADAR THIN LAYERS OVER FOAM STABILIZED BASE LAYERS

ACCURACY OF GEORADAR OUTPUT RESULTS IS BASIC FOR BACKCALCULATION PROCESS.

NOISE DUE… EFFE…



IT IS VERY DIFFICULT TO DETECT SUPERFICIAL THIN LAYERS

1. ABILITY TO IDENTIFY WITH GROUND PENETRATING RADAR THIN LAYERS OVER FOAM STABILIZED BASE LAYERS

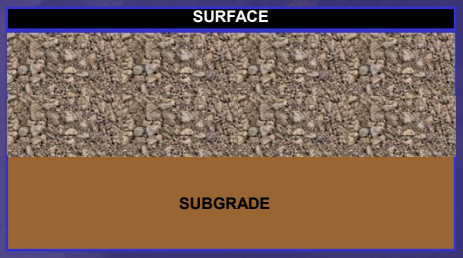
HD 29/94 Vol. 7 Section 3 Part. 2

…An under-estimate of as little as ***FIFTEEN*** *percent in thickness, which is not uncommon given construction thickness, car result in an over-estimate of over* ***FIFTY*** *percent in bound-layer moduli values,* ***enough to give the impression of good integrity of a poor layer…***

ACCURATE MEASUREMENT OF LAYER THICKNESSES IS REQUESTED!!!

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

2. RESPECT OF THE THEORETICAL RULE FOR BACKCALCULATION: MODULI SHOULD DECREASE WITH DEPTH



FOR SOME COMBINATIONS OF ASPHALT TEMPERATURE-CR LAYERS CURING CONDITIONS, THE STIFFNESS MODULUS OF SECOND LAYER CAN BE HIGHER THAN THE FIRST ONE.

INTERNATIONAL GUIDELINES FOR PAVEMENT REABILITATION WITH COLD RECYCLING TECHNIQUE

MINIMUM THICKNESS REQUIRENTS – (AUSTRLIA): the standard practice is to apply a 30 mm thick asphalt layer over the foamed bitumen stabilized layer. Dense grade and stone mastic asphalt has been placed onto the foam surface. Local practitioners may recommend a sprayed seal if traffic is less than 10^6 ESAL.

TG2 2009 STRUCTURAL DESIGN METHOD - The authors of the method recommend that bituminous stabilized layers should be surfaced with a sprayed seal if the traffic is less than 1 x 10^6 ESA. For traffic between 1 x 10^6 and 15 x 10^6 they recommend a hot mix asphalt layer. For traffic exceeding 15 x 10^6 ESAL, a hot mix asphalt thickness of at least 50 mm is recommended.

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

2. RESPECT OF THE THEORETICAL RULE FOR BACKCALCULATION: MODULI SHOULD DECREASE WITH DEPTH

ITALIAN NATIONAL AUTONOMOUS COMPANY FOR ROADS (ANAS)

11 cm OF BITUMINOUS MIXTURE OVER 45 CM (20 EMULSION, 25 FOAM) OF RECYCLED LAYER. TRAFFIC = **18·10⁶** EQUIVALENT AXLE LOAD

11 cm OF BITUMINOUS MIXTURE OVER 40 CM (20 EMULSION, 20 FOAM) OF RECYCLED LAYER. TRAFFIC = **10·10⁶** EQUIVALENT AXLE LOAD

ITALIAN TECHNICAL PRESCRIPTIONS

…It was reported that two agencies using the same compueter program derived very different back-calculated results for the same pavement cross section (Lytton and Chou, 1998). This is true for thin layers because the deflections basin in insensitive to their moduli ***and a good match between computed and measured deflection can be obtained even if totally unreasonable moduli are derived for these thin layers****…*

Engineering judgments play an important role in such situations!!

PAVEMENT ANALYSIS AND DESIGN – Yang H. Huang

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

STRATEGIES AND SOLUTIONS

HOW CAN WE SOLVE (OR LIMIT) THESE PROBLEMS?

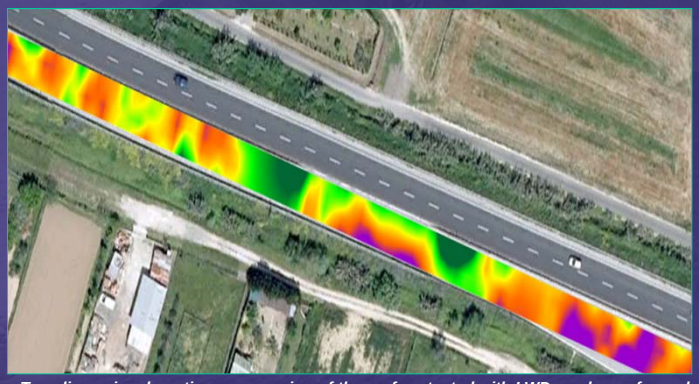
IS IT POSSIBLE TO DEVELOPE STRATEGIES TO FACE EACH PARTICULAR ASPECT RELATED TO PAVEMENT CONTAINING COLD RECYCLED LAYERS?
(thin asphalt layers – evolution in stiffness over time – temperature susceptibility -....)

POSSIBLE SOLUTIONS:

1. USE THE LWD DURING CONTRUCTION AT DIFFERENT CURING TIME
2. FIX THE ASPHALT SURFACE MODULUS - BACKCALCULATION PROCESS
3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS
4. SCHEDULE DEFLECTION SURVEY TAKING INTO ACCOUNT FOR COLD RECYCLED LAYER CURING TIME AND CLIMATIC CONDITIONS

IN SITU COLD RECYCLING OF THE FREEWAY FI.PI.LI. (ITALY)

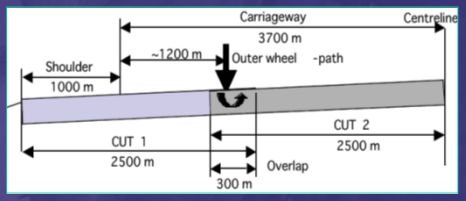
LWD can be applied to perform a control of the short term bearing capacity of the layer along its longitudinal development and the uniformity in the transverse direction that is influenced by some constructive issues that must be real-time considered, (i.e. *overlap between adjacent cuts)*

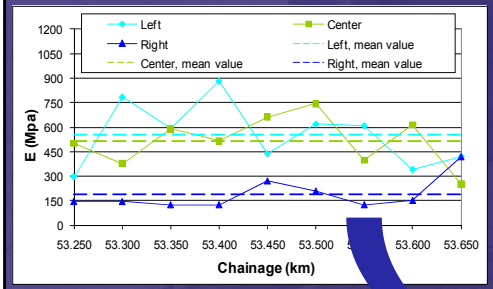


Two-dimensional continuous mapping of the surface tested with LWD can be performed

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

OVERLAP BETWEEN ADJACENT CUTS

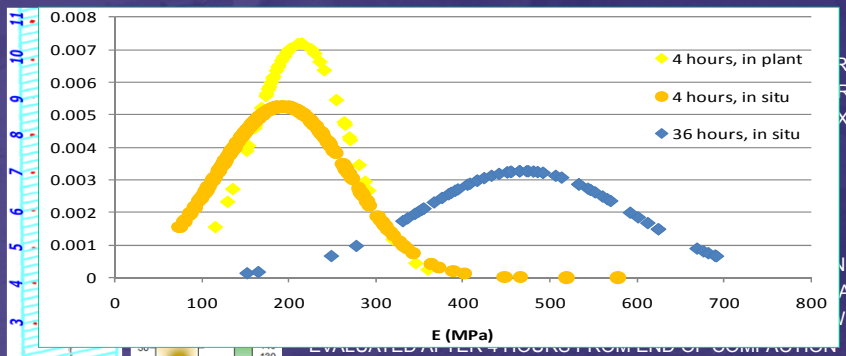




The performance of the right track of a lane detecte[illegible]r 3 different tracks is noticeably lower of the ones obtaine[illegible] the other two tracks

1. USE THE LWD DURING CONTRUCTION AT DIFFERENT CURING TIME

CASE HISTORIES:



RENT
RSAL
X10.0

NCED
AMIC
/HEN

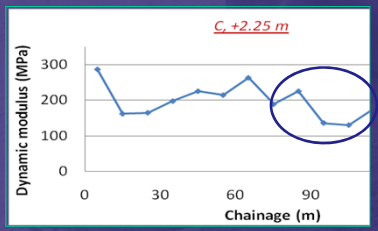
UTION FOR LWD DATA REGISTERED FOR TWO DIFFERENT COLD-
PLANT AND IN SITU) AFTER 4 HOURS FROM COMPACTION, IT CAN
, **DISPERSION OF RESULTS IS HIGHER FOR IN SITU RECYCLED**
IFIRM THAT IN PLANT RECYCLING ALLOW A MORE SELECTION OF
MATERIAL AND A SIGNIFICANT HOMOGENEITY OF STIFFNESS VALUES

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

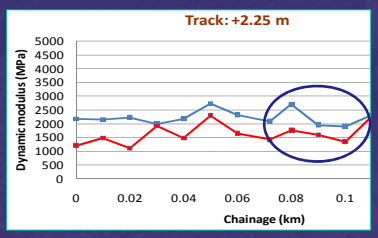
1. USE THE LWD DURING CONTRUCTION AT DIFFERENT CURING TIME

CASE HISTORIES:

LWD test results provide useful information on *short term performance* of cold recycled layers and *a reliable prevision of the pavement performance* expected with FWD final controls can be assessed.

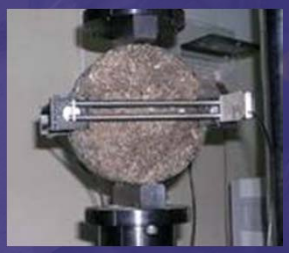


LWD



FWD

2. FIX THE ASPHALT SURFACE MODULUS - BACKCALCULATION PROCESS



IS POSSIBLE TO FIX THE VALUE OF SURFACE ASPHALT MODULUS. TESTS IT-CY FOR STIFFNESS DYNAMIC MODULUS CAN BE UNDERTAKEN:

"Research has shown that there is a strong association between ITSM values and bituminous layers stiffnesses estimated form FWD back-analysis."**-HD 29/94 Part 2, Volume 7, Section 3.**

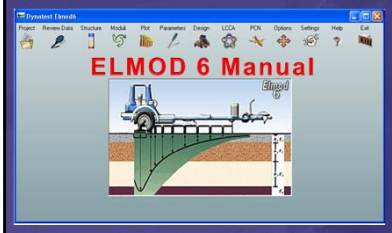
"As an appropriate guide, ITSM values at 20°C should multiplied by **1.5** to allow comparison with FWD-derived bituminous layer stiffness at 20°C."**-HD 29/94 Part 2, Volume 7, Section 3.**

MR = 1.7*EFWD +1900 (MPa) – University of Pisa - SIIV Conference (Italy 2007)

MASTER CURVE OF THE MIXTURE IS REQUIRED TO REPORT THE STIFFNESS VALUE TO FWD TESTING FREQUENCY

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

2. FIX THE ASPHALT SURFACE MODULUS - BACKCALCULATION PROCESS



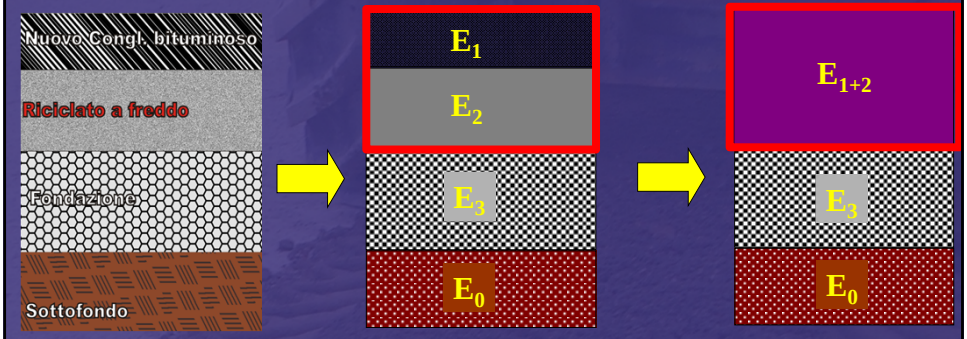
There are some limitations to backcalculation of layer moduli. Several pavement structures (different combinations of layer stiffness) may result in the same deflection bowl and the process may output any one of these solutions. The user can assist the process by specifying suitable limits for layer stiffness and seed values for the iterative process.

ENGIHEERING JUDGEMENT SHOULD ASSIST THE BACKCALCULATION PROCESS. RESULTS CAB BE SUBJECTIVE…

*For 3-layer systems it may occur, particularly if the moduli of the two pavement layers are similar or if the modulus of the intermediate layer is close to the modulus of the subgrade. **It may also occur with thin layers**. For 4 and 5-layer systems the same deflection bowl can often be obtained with different combinations of layer moduli. **For these cases the deflection** nd additional information is a fixed modulus for one or combining similar layers.*

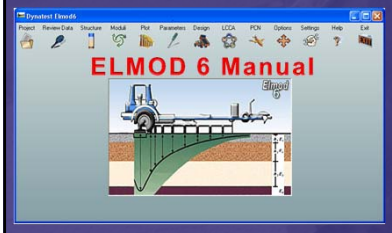
VERY OFTEN THIS ADDITIONAL INFORMATION ARE RIGHT OUR GOAL

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS



DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS



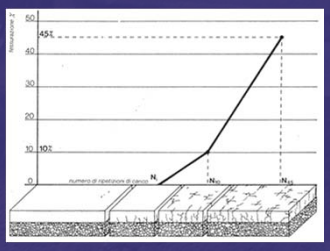
DIFFERENT ASPHALT MATERIALS, SUCH AS WEARING COURSE, BINDER COURSE AND BASE COURSE <u>SHOULD ALWAYS BE COMBINED INTO ONE LAYER</u> FOR THE PURPOSE OF CALCULATING THE EXISTING MODULI.

ASPHALT LAYER

*When two or more materials are combined to form one layer the moduli should preferably be of the <u>**SAME ORDER OF MAGNITUDE**</u>.*

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

COMBINING A RECYCLED LAYER AND AN ASPHALT LAYER INVOLVE OTHER PROBLEMS



✓ DIFFERENT LONG TERM BEHAVIOUR

✓ DIFFERENT TEMPERATURE SENSITIVITY

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

TG2 2002 GUIDELINES (SOUTH AFRICA): This method, published in 2002, was developed using testing data from a full-scale accelerated testing of foamed bitumen pavements and extensive laboratory work. The TG2 2002 Guidelines method suggests that foamed bitumen pavements behave in two separate phases. The first phase starts after construction, when the layer is in an intact, undamaged condition and provides fatigue resistance. This phase is called '**effective fatigue phase**' and ends when, due to the applied loading, the layer reduces its stiffness. The second phase is called '**equivalent granular state**', because the stiffness of the foamed bitumen layer is similar to that of a good quality granular base. The assumed distress modes of the first and second phase are fatigue and permanent deformation, respectively.

DEPARTMENT OF TRANSPORT AND MAIN ROADS, QUEENSLAND (AUSTRALIA) TMR adopted the **Austroads asphalt fatigue relationship for the foamed bitumen layer**. The asphalt fatigue relationship relates the admissible number of load cycles with the volumetric properties of the mix, the stiffness of the mix and the tensile strain at the bottom of the foamed bitumen layer. The method assumes that fatigue is the primary distress mode.

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

AUSTRALIA: The City of Canning developed a fatigue relationship for foamed bitumen layers using data from flexural beams prepared and compacted in the field and tested in the laboratory. It was found that the fatigue relationship is independent of the stiffness of the mixes.

TRANSPORTATION RESEARCH LABORATORY (UNITED KINGDOM): The TRL method assumes that foamed bitumen mixes behave similarly to hot mix asphalt mixes, fatigue being the dominant distress mode of these mixes. The method is based on tables and charts that classify subgrade, traffic and foamed bitumen type. These assumptions are mainly based on engineering judgment.

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

NZ TRANSPORT AGENCY (NEW ZEALAND) The NZ Transport Agency (NZTA) design procedure suggests that fatigue relationships are too conservative and do not represent the observed behaviour in New Zealand foamed bitumen pavements. Pavement designers in New Zealand normally consider the foamed bitumen layer as an unbound granular layer. The method recommends an elastic modulus of 800 MPa (anisotropic, no sub-layering) for the modelling of the elastic properties of the foamed bitumen layer. The pavement thickness is calculated by reducing the vertical compressive strain at the top of the subgrade to the value obtained by the Austroads subgrade strain criteria.

AIPCR PAVEMENT RECYCLING 2003: For design calculation with a multi-layer elastic model, it is necessary to allot the layer of recycled material representative value for Young Modulus and Poisson's ratio. ..the design criterion is often a limit value for the vertical resilient Ɛz at the subgrade level…

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

SELF PRESERVATION OF FOAMED ASPHALT TRETAED MIXTURE

Design and performance analysis of foamed asphalt treated mixtures
MARRADI ET.AL ITCI 2010

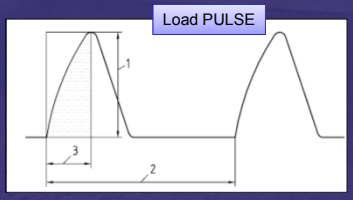
DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

WITH THE PURPOSE TO INVESTIGATE THE "SELF PRESERVATION BEHAVIOUR" SEVERAL SPECIMENS OF FOAM STABILIZED TREATED MIX WERE TESTED ADOPTING AN IT-CY CONFIGURATION, EACH SUBJECTED TO A DIFFERENT STRESS LEVEL, NAMELY A DIFFERENT VALUE OF INITIAL DEFLECTION.

$$S_m = \frac{F \cdot (\nu + 0.27)}{z \cdot h}$$



UNI EN 12697-26, IT-CY TEST CONFIGURATION

SM = STIFFNESS MODULUS (MPA), F = PEAK LOAD (N), v = POISSON'S RATIO, Z = HORIZONTAL STRAIN (mm), H = SPECIMEN HEIGHT (mm).

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

FOR EACH STRESS LEVEL THE VALUES CAN BE INTERPOLATED WITH GOOD ACCURACY USING EXPONENTIAL LAWS, HENCEFORTH CALLED "**DECAY CURVES**" .

WITH INCREASING NUMBER OF LOAD CYCLES, A DECREASE IN STIFFNESS MODULUS WAS NOTICED; THIS DECREASE IS SHARPER WITH INCREASINGLY ELEVATED VALUES OF APPLIED STRESS, UP TO BREAKING POINT.

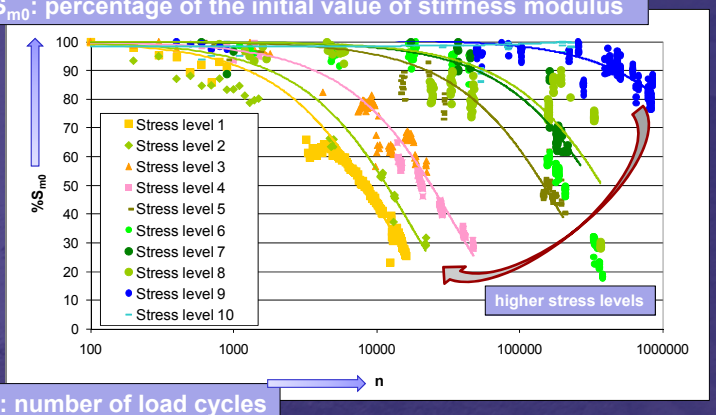
DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

DECAY CURVES

$\%S_{m0}$: percentage of the initial value of stiffness modulus



n: number of load cycles

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT LONG TERM BEHAVIOUR

THIS MEANS THAT A FOAMED ASPHALT TREATED LAYER IS CHARACTERIZED BY A **REDUCTION IN STIFFNESS RESULTING FROM REPEATED TRAFFIC LOADS AND CONSEQUENTLY BY A DECREASE IN STRESS**, DIFFERENTLY TO THE OTHER MATERIALS OF THE PAVEMENT, WHICH ACCUMULATE MORE STRESS. IN FACT, THERE ARE STUDIES THAT ATTRIBUTE TO UNBOUND MATERIALS AND TO ASPHALT CONCRETE A NEGLIGIBLE DROP OF STIFFNESS DURING THE EARLY USEFUL LIFE OF THE PAVEMENT.

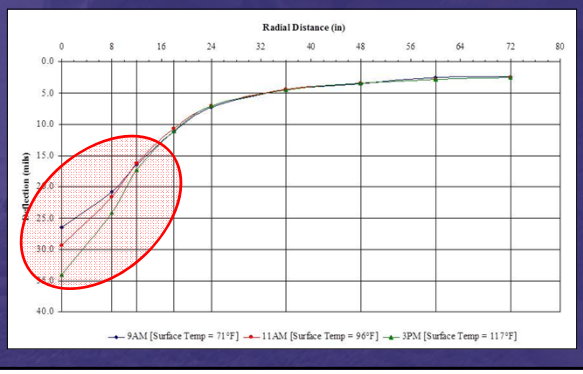
THUS FOAMED ASPHALT TREATED MIXTURES SHOW A "SELF-PRESERVATION" BEHAVIOUR DURING THE USEFUL LIFE OF THE PAVEMENT, SINCE THERE IS A DECREASE IN STIFFNESS AND THEREFORE ALSO IN STRESS LEVEL. THE PERFORMANCE WILL CONSEQUENTLY BE BETTER THAN THAT INFERRED ON THE BASIS OF CLASSICAL FATIGUE TESTS, DURING WHICH THE LOAD APPLIED HAS A CONSTANT PEAK VALUE.

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

3. COMBINE ASPHALT LAYER WITH RECYCLED LAYER - BACKCALCULATION PROCESS

DIFFERENT TEMPERATURE SENSITIVITY

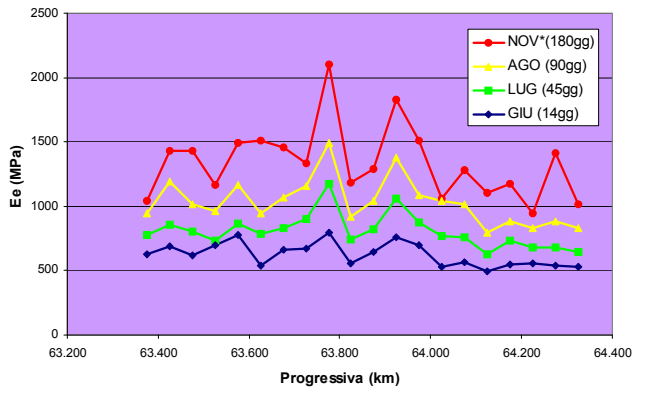
EVERY BITUMINOUS BOUND MATERIALS SHOW A GREAT DEPENDANCY ON TEMPERATURE. THIS MEANS DEFLECTION MAGNITUDE OF LAYERS VARY MAKEDLY VARING INSIDE TEMPERATURE. FOR THIS REASON STIFFNESS VALUE FOR ASPHALT LAYERS MUST BE EDIT TO 20°C REFERENCE TEMPERATURE.



4. SCHEDULE DEFLECTION SURVEY TAKING INTO ACCOUNT FOR COLD RECYCLED LAYER CURING TIME AND CLIMATIC CONDITIONS

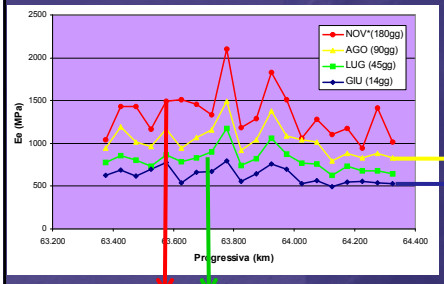
Generally prescriptions report a different stiffness to be reached according the curing time at the moment of the test.

Curing Time	Modulus [MPa]
from 12 to 24 hours	300
from 24 to 48 hours	500
after 90 days	3000



DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

4. SCHEDULE DEFLECTION SURVEY TAKING INTO ACCOUNT FOR COLD RECYCLED LAYER CURING TIME AND CLIMATIC CONDITIONS



Several backcalculation problems – no difference in stiffness

July (45 days) – similar low stiffness values

November (180 days) – similar high stiffness values

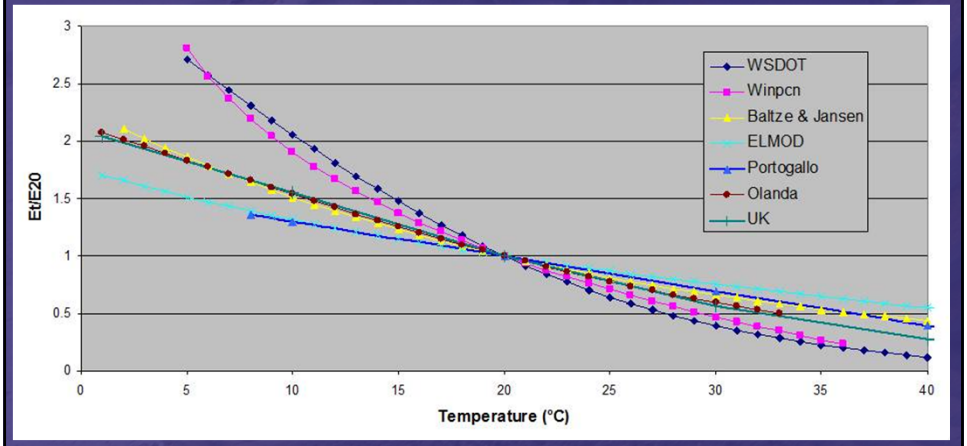
No backcalculation problems – high difference in stiffness

June (14 days):
Low stiffness of recycled layer due to short curing time – significant difference in stiffness with asphalt layers

August (90 days)
Low stiffness of asphalt layers due to the high test temperature
Relatively hig stiffness of cold recycled layer

4. SCHEDULE DEFLECTION SURVEY TAKING INTO ACCOUNT FOR COLD RECYCLED LAYER CURING TIME AND CLIMATIC CONDITIONS

DIFFERENT TEMPERATURE SENSITIVITY



EDIT TO REFERENCE TEMPERATURE

DEFLECTION MEASUREMENT ON COLD RECYCLING PROJECT AND FWD ANALYSIS
Alessandro Marradi

4. SCHEDULE DEFLECTION SURVEY TAKING INTO ACCOUNT FOR COLD RECYCLED LAYER CURING TIME AND CLIMATIC CONDITIONS

DIFFERENT TEMPERATURE SENSITIVITY

ASPHALT INSTITUTE FORMULA

$$E_{Ts} = 10^{\alpha \cdot (T^2 - T_S^2)} \times E$$

α REPRESENT THE THERMAL SUSCEPTIBILITY OF THE MIX

FOR ASPAHLT CONCRETE → 0.0001÷0.000147 DEPENDING ON PAVEMENT AGING

COLD RECYCLED MATERIALS WITH FOAM AND/OR EMULSION → 0.00006÷0.00007 DEPENDING ON BITUMEN CONTENT

These values can be estimated by making several FWD tests on the same test position at different temperature

QUESTIONS?

ALESSANDRO MARRADI, ASSISTANT PROFESSOR UNIVERSITY OF PISA

CIVIL ENGINEERING DEPARTMENT

LARGO LAZZARINO - 56126 PISA ITALY

MOBILE: +39 339 3009148 PHONE: +39 050 2217747

EMAIL: a.marradi@ing.unipi.it