

1



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O que é o Modelo de Predição de Vida Útil ?

Um consenso, ferramenta imparcial, “aberta”, que habilita projetistas, proprietários, agências governamentais, etc. a utilizar um modelo de projeto de proteção contra a corrosão do aço, avaliando critérios alternativos em base de desempenho, para projetar uma estrutura de concreto armado com um período de vida acima do especificada.

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Modelo de Predição de Vida Útil de Serviço

(Equação Básica - Fick)

$$\frac{dC}{dt} = D \bullet \frac{d^2 C}{dx^2}$$

C = Cloreto “livre” em solução

D = Coeficiente de Difusão Aparente

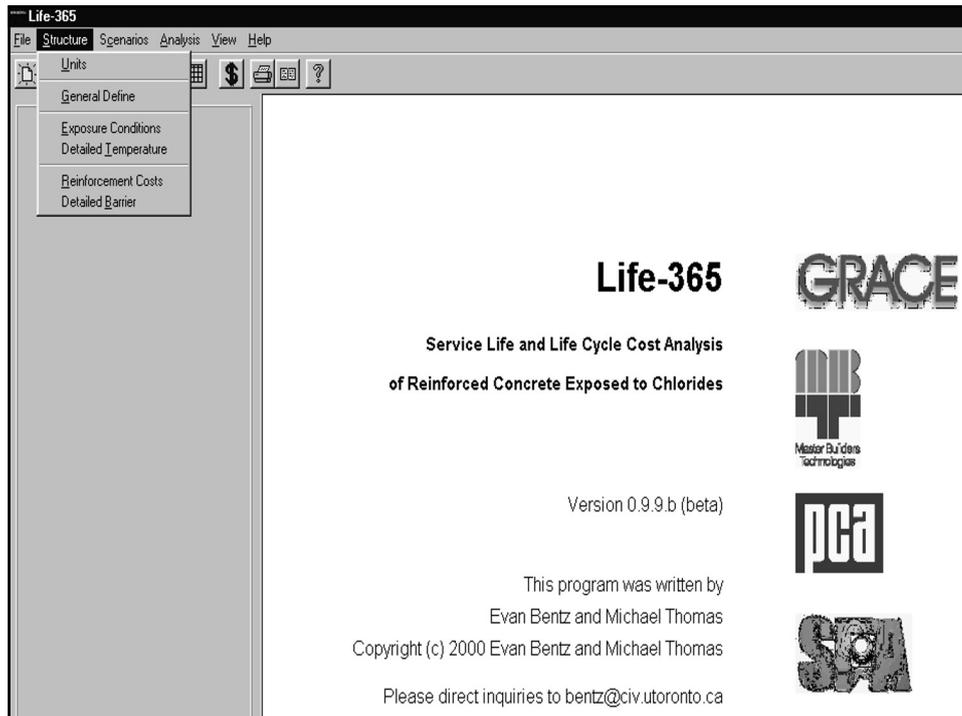
x = Capa de Cobrimento da Armadura

t = Tempo

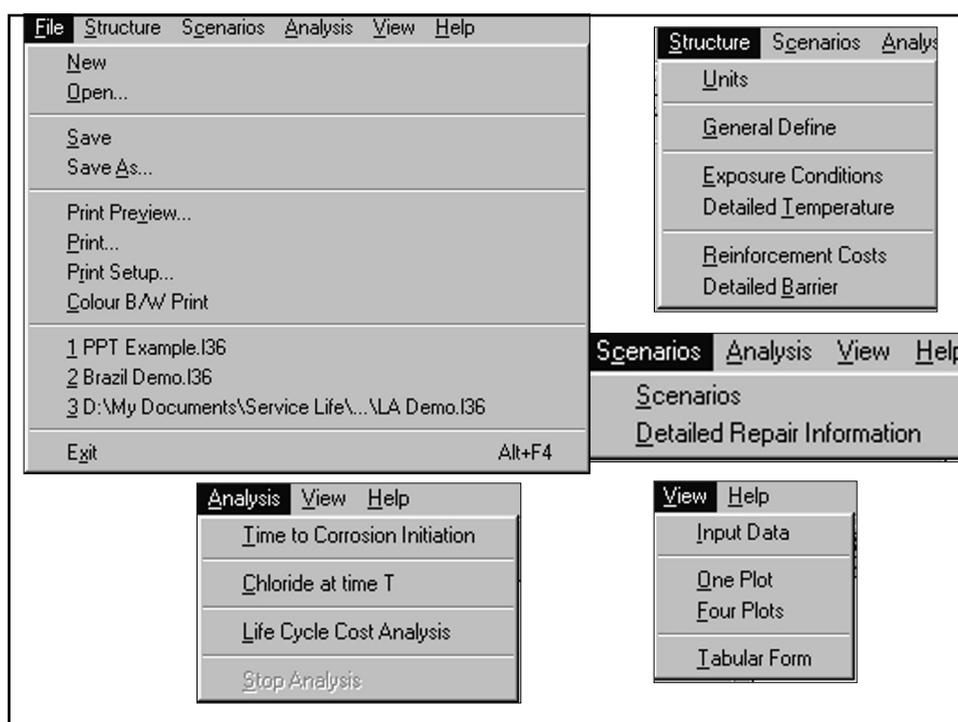
4



5

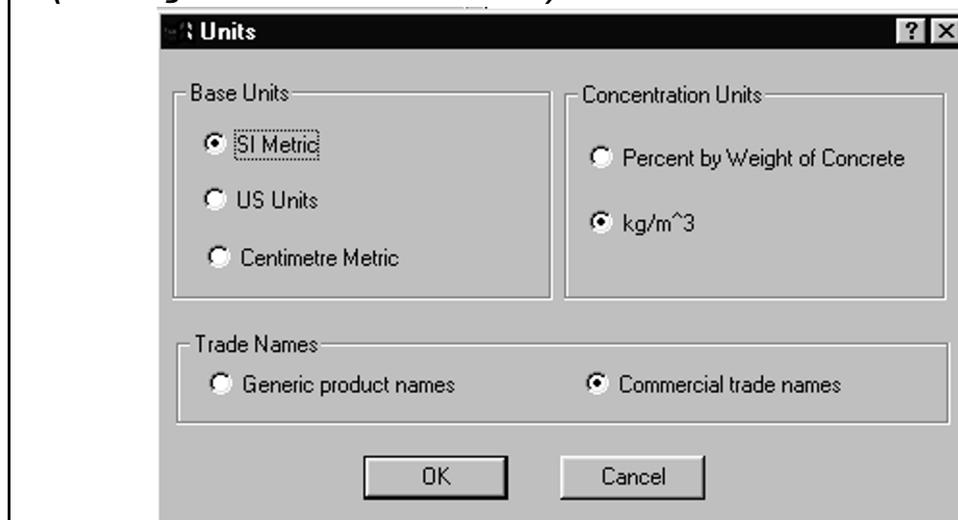


6



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Modelo de Predição de Vida Útil de Serviço (Seleção das Unidades)



8

Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 1 of 3

Title and General Comments

Port of Project / Beachfront Hotel Complex

Done By Date

Type of Structure

1-Dimensional chloride loading (Slabs and Walls)

2-Dimensional chloride loading (Square Column/Beam for Corner Bars)

2-Dimensional chloride loading (Circular Columns for outer bars or hoc

< Back Next > Cancel

Quantidade de injeção de cloritos em volume ou multiplas faces

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Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 2 of 3

Structure Dimensions

Overall Thickness mm Clear Cover mm

Base Concrete Type (with respect to total cementitious material)

Water Cement Ratio Silica Fume %age

Slag Percentage

Class F Fly Ash %age

Base Rebar Type

Select from list

Total percentage Percent

< Back Next > Cancel

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Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 3 of 3

Long Term Exposure

Location: Puerto Rico | SAN JUAN

Exposure: Marine Spray Zone

Base Case Cost: Marine Tidal Zone
Parking Garages
Rural Highway Bridges
Urban Highway Bridges
Within 1.5 km of Ocean

Base Mix Cost: []

Repair Cost: 400.0 Dollars per square metre

Area to Repair: 10.0 Percentage of total area

Repair Interval: 10.0 years

Discount Rate: 3.0 percent

Design Life: 75.0 years

< Back Finish Cancel

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Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 3 of 3

Long Term Exposure

Location: California | SAN FRANCISCO

Exposure: Marine Tidal Zone

Base Case Cost: Marine Tidal Zone
Marine Spray Zone
Parking Garages
Rural Highway Bridges
Urban Highway Bridges

Base Mix Cost: []

Repair Cost: 400.0 Dollars per square metre

Area to Repair: 10.0 Percentage of total area

Repair Interval: 10.0 years

Discount Rate: 3.0 percent

Design Life: 75.0 years

< Back Finish Cancel

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Névoa Salina / Zona de Maré



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Névoa Salina / Zona de Maré



14

Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 3 of 3

Long Term Exposure

Location: Puerto Rico | SAN JUAN

Exposure: Marine Spray Zone

Base Case Cost: Parking Garages, Rural Highway Bridges, Urban Highway Bridges, Within 1.5 km of Ocean, Within 800 m of Ocean

Base Mix Cost: []

Repair Cost: 400.0 Dollars per square metre

Area to Repair: 10.0 Percentage of total area

Repair Interval: 10.0 years

Discount Rate: 3.0 percent

Design Life: 75.0 years

< Back Finish Cancel

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Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 3 of 3

Long Term Exposure

Location: California | SAN FRANCISCO

Exposure: Marine Tidal Zone

Base Case Cost: Parking Garages, Rural Highway Bridges, Urban Highway Bridges, Within 1.5 km of Ocean, Within 800 m of Ocean

Base Mix Cost: []

Repair Cost: 400.0 Dollars per square metre

Area to Repair: 10.0 Percentage of total area

Repair Interval: 10.0 years

Discount Rate: 3.0 percent

Design Life: 75.0 years

< Back Finish Cancel

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Windborne Exposição à Cloretos



17

Windborne Exposição à Cloretos



18

Windborne Exposição à Cloretos



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Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 3 of 3

Long Term Exposure

Location: Puerto Rico | SAN JUAN

Exposure: Marine Spray Zone

Base Case Cost Information

Base Mix Cost	100.0	Dollars per cubic metre
Repair Cost	400.0	Dollars per square metre
Area to Repair	10.0	Percentage of total area
Repair Interval	10.0	years
Discount Rate	3.0	percent
Design Life	75.0	years

< Back Finish Cancel

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Modelo de Predição de Vida Útil (Definições Gerais)

General Define - Step 3 of 3

Long Term Exposure

Location: California SAN FRANCISCO

Exposure: Marine Tidal Zone

Base Case Cost Information

Base Mix Cost: Dollars per cubic metre

Repair Cost: Dollars per square metre

Area to Repair: Percentage of total area

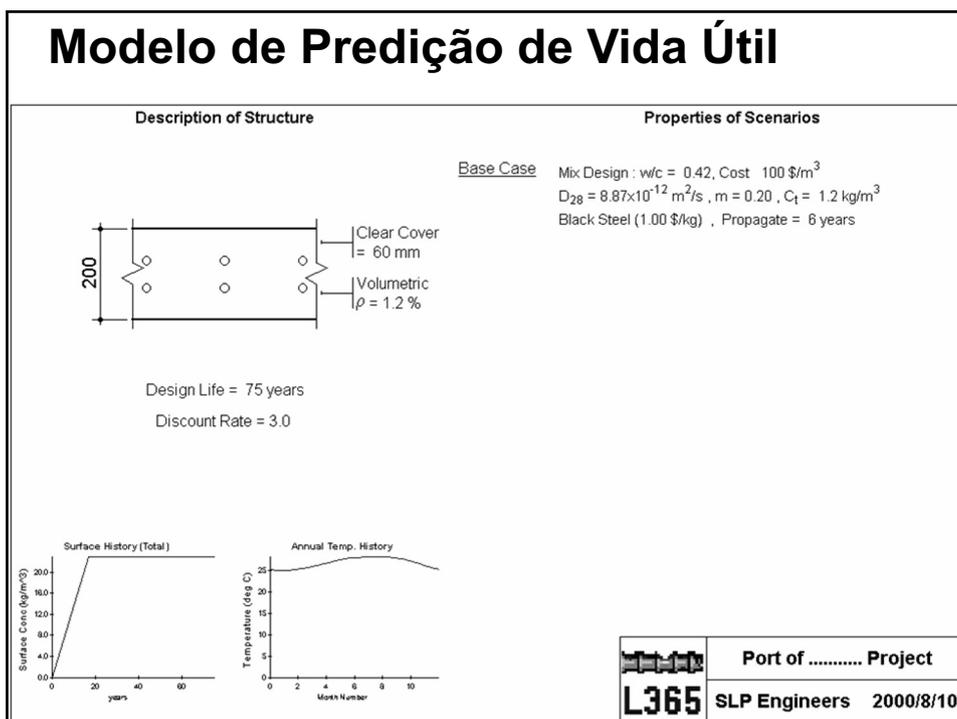
Repair Interval: years

Discount Rate: percent

Design Life: years

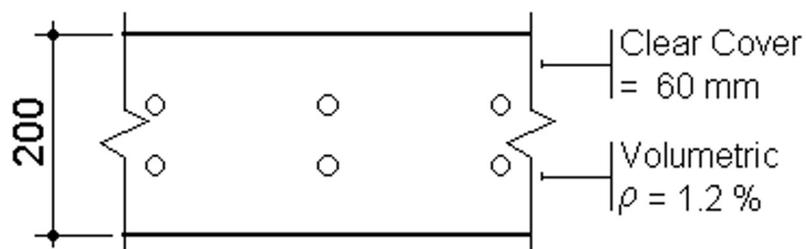
21

Modelo de Predição de Vida Útil



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Modelo de Predição de Vida Útil (Descrições Gerais)

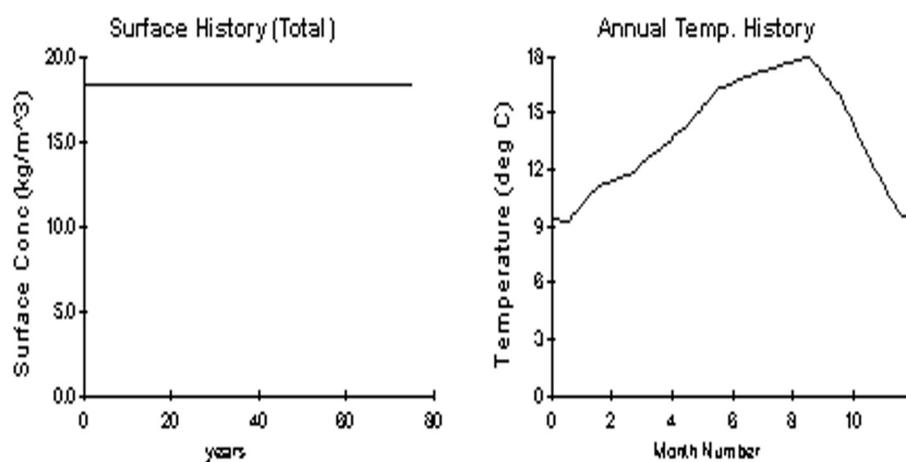


Design Life = 75 years

Discount Rate = 3.0

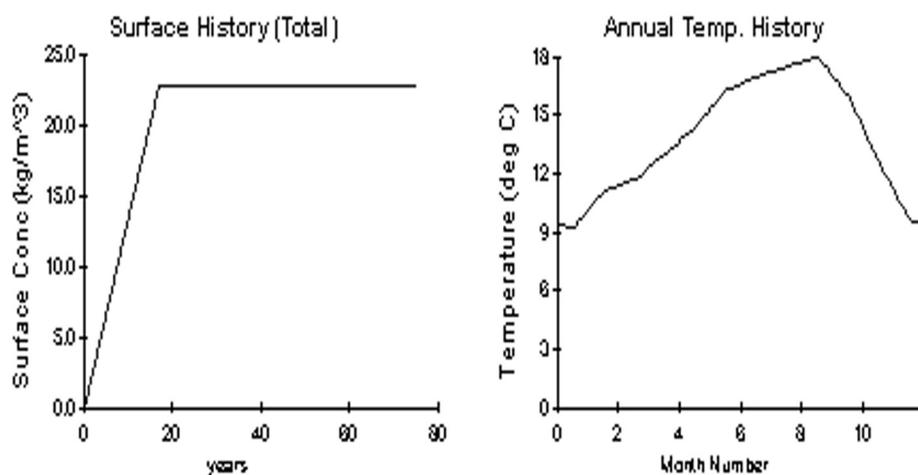
23

Modelo de Predição de Vida Útil (Historico de Condições de Exposição)



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Modelo de Predição de Vida Útil (Historico de Condições de Exposição)



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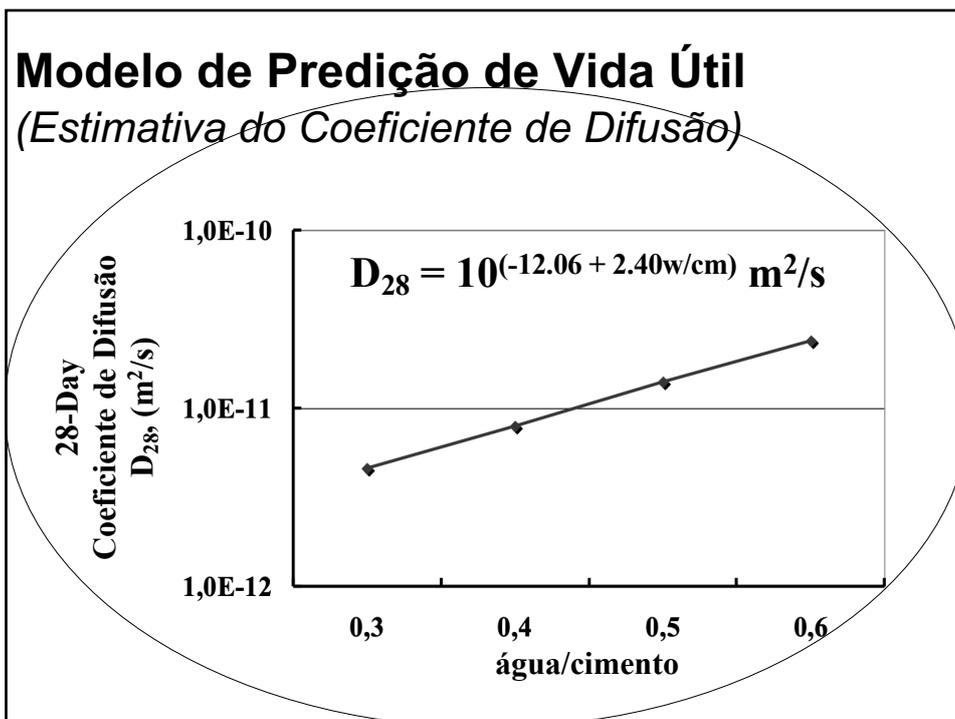
Modelo de Predição de Vida Útil (Resumo da Entrada de Dados)

Base Case Mix Design : w/c = 0.40, Cost 100 \$/m³
 $D_{28} = 7.94 \times 10^{-12} \text{ m}^2/\text{s}$, $m = 0.20$, $C_t = 1.16 \text{ kg/m}^3$
 Black Steel (0.66 \$/kg) , Propagate = 6 years

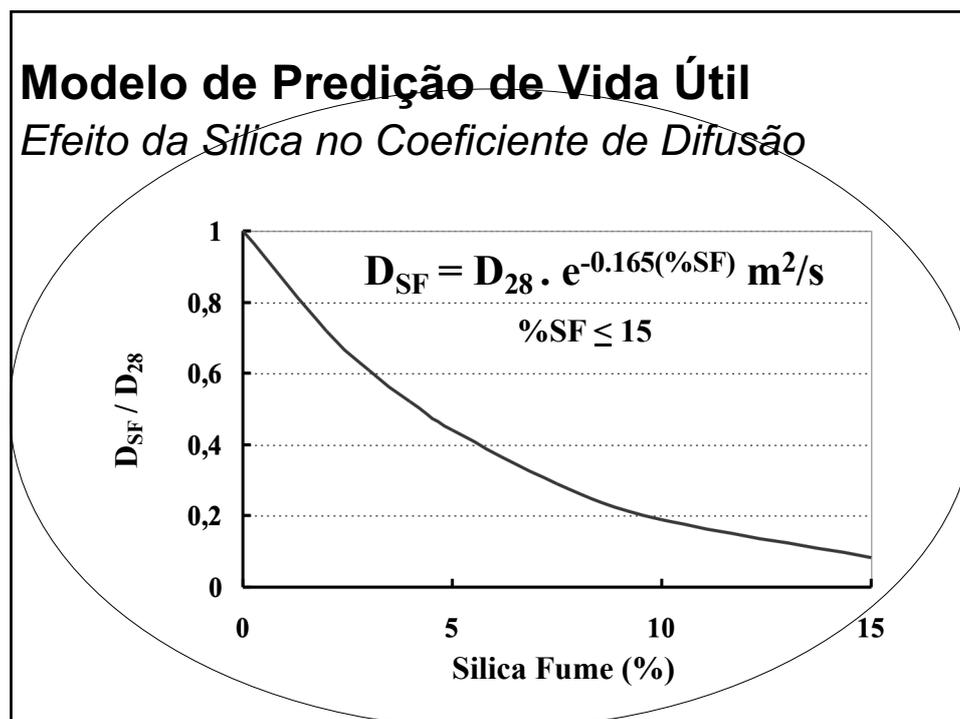
—
Coefficiente de difusão aos 28 Dias

(.....função do fator água/cimento
 & Teor de Silica)

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Modelo de Predição de Vida Útil

(Resumo da Entrada de Dados)

Base Case Mix Design : w/c = 0.40, Cost 100 \$/m³
 $D_{28} = 7.94 \times 10^{-12} \text{ m}^2/\text{s}$, $m = 0.20$, $C_t = 1.16 \text{ kg/m}^3$
 Black Steel (0.66 \$/kg) , Propagate = 6 years

/
Diffusion Decay Exponent
 (.....Varies for Fly Ash & Slag)

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Modelo de Predição de Vida Útil

*Efeito do Fly Ash & Escória na
 Queda da Difusão, m*

$$m = 0.2 + 0.4 \left\{ \frac{\%FA}{50} + \frac{\%SG}{70} \right\}$$

$$\begin{matrix} \%FA \leq 50 \\ \%SG \leq 70 \end{matrix} \implies m \leq 0.60$$

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Modelo de Predição de Vida Útil

*Effect of Fly Ash & Slag on
Diffusion Coefficient over Time*

$$D_{ult} = D_{ref} \cdot \left(t_{ref} / t_{ult} \right)^m$$

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Modelo de Predição de Vida Útil

*Efeito do Fly Ash & Slag no
Coeficiente de Difusão ao longo do tempo*

$$D(t) = D_{ref} \cdot \left(t_{ref} / t \right)^m + D_{ult} \left[1 - \left(t_{ref} / t \right)^m \right]$$

D(t) = Coeficiente de Difusão ao tempo, t
ult = 100% Hidratação (= 100 anos no Life 365)
ref = Tempo de Referência (= 28 dias no Life 365)
m = Difusão -Fator de decréscimo

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Modelo de Predição de Vida Útil (Resumo da Entrada de Dados)

Base Case Mix Design : w/c = 0.40, Cost 100 \$/m³
 $D_{28} = 7.94 \times 10^{-12} \text{ m}^2/\text{s}$, m = 0.20 , $C_t = 1.16 \text{ kg/m}^3$
 Black Steel (0.66 \$/kg) , Propagate = 6 years

|
Limite de Cloreto
 (...Affected by Corrosion Inhibitors & Stainless Steel)

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Modelo de Predição de Vida Útil Efeito do Inibidor de Corrosão & Aço Inoxidável Steel no Limite de Cloreto

Sistemas de Proteção Protection de Corrosão system	Limite de Cloreto, C_t (% por massa de concreto)
Base Concrete	0.05
Inibidor de Nitrito de Cálcio @ 10, 15, 20, 25, 30 L/m³	0.15, 0.24, 0.32, 0.37, 0.40
Inibidor Orgânico Ester/ Amina @ 5 L/m³	0.12
Aço Inoxidável	0.50

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Modelo de Predição de Vida Útil (Histórico de Exposição à Cloreto)

Exposure Conditions [?] [X]

Automatic exposure selection

Max surface concentration kg/m³

Time to build up to this level years

Age at first exposure days

Month of first exposure (for temp) (0 - 11.9)

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Modelo de Predição de Vida Útil (Exposição à Cloreto)

Exposure Conditions [?] [X]

Automatic exposure selection

Max surface concentration kg/m³

Time to build up to this level years

Age at first exposure days

Month of first exposure (for temp) (0 - 11.9)

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Modelo de Predição de Vida Útil (Histórico de Temperatura)

Enter Monthly Temperature History

Month # Temperature Celsius

Month #	Temperature
0.5	9.3
1.5	11.2
2.5	11.8
3.5	13.1
4.5	14.5
5.5	16.4
6.5	17.1

Buttons: Add, Modify, Delete, OK, Cancel

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Modelo de Predição de Vida Útil Efeito da Temperatura no Coeficiente de Difusão

$$D(T) = D_{\text{ref}} \cdot \exp \left[\frac{U}{R} \cdot \left(\frac{1}{T_{\text{ref}}} - \frac{1}{T} \right) \right]$$

D(T) = Coeficiente de Difusão a temperatura T
D_{ref} = Coeficiente de Difusão ao tempo de referencia **t_{ref}**
T_{ref} = Temperatura de Referencia
U = Energia para Ativação do processo de difusão
 (35000 J/mol)
R = Gas constante
T = Temperatura Absoluta

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Modelo de Predição de Vida Útil (Aço / Custo da Proteção de Superfície)

Rebar Costs [?] [X]

Automatic cost selection

Cost of Black Steel	<input type="text" value="0.66"/>	\$/kg
Cost of stainless steel	<input type="text" value="6.50"/>	\$/kg
Cost of epoxy coated steel	<input type="text" value="1.50"/>	\$/kg
Cost of 5 year membrane	<input type="text" value="13.00"/>	\$/m ²
Cost of 3 year sealer	<input type="text" value="6.50"/>	\$/m ²

OK Cancel Help

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Modelo de Predição de Vida Útil (Detalhes da Barreira de Superfície)

Detailed Barrier Properties [?] [X]

Detailed Properties

Barrier Types	Barrier Definition
Name: <input type="text" value="None"/>	Area Cost: <input type="text" value="0.00"/> \$/m ² (eg: 10.00)
Defined Types	Initial Efficiency: <input type="text" value="0"/> percent (eg: 90)
Add	Age at Failure: <input type="text" value="1.0"/> years (eg: 0.0)
Modify	Reapply Time: <input type="text" value="0.0"/> years (eg: 15.0)
Delete	
None	
Membrane	
Sealer	
User 1	
User 2	

OK Cancel Apply

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Modelo de Predição de Vida Útil (Criando Argumentos para Análise.....)

The screenshot shows the 'Scenarios Definition' dialog box with the 'User Defined' tab selected. The 'Scenario List' on the left contains one entry, 'Base Case'. The 'Scenario Definition' on the right is configured as follows:

Parameter	Value	Unit	Example
Concrete Cost	100.00	\$/m ³	(eg: 100.00)
W/C Ratio	0.40		(eg: 0.35)
% Class F Fly Ash	0	percent	(eg: 20)
% Slag	0	percent	(eg: 20)
% Silica Fume	0	percent	(eg: 8)
Concrete Protection	None		
Rebar Protection	Black Steel		
Barrier	None		

Buttons at the bottom: OK, Cancel, Apply.

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Modelo de Predição de Vida Útil (Criando Argumentos para Análise.....)

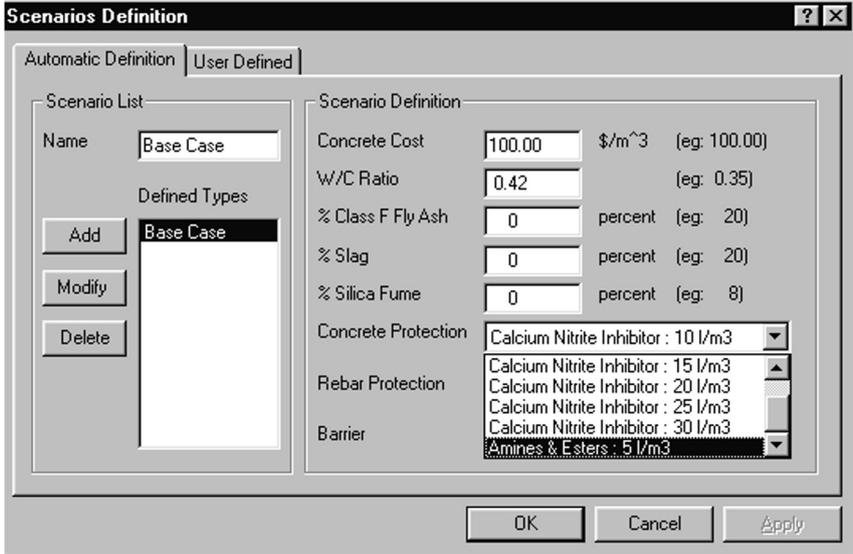
The screenshot shows the 'Scenarios Definition' dialog box with the 'User Defined' tab selected. The 'Scenario List' on the left contains one entry, 'Base Case'. The 'Scenario Definition' on the right is configured as follows:

Parameter	Value	Unit	Example
Concrete Cost	100.00	\$/m ³	(eg: 100.00)
W/C Ratio	0.42		(eg: 0.35)
% Class F Fly Ash	0	percent	(eg: 20)
% Slag	0	percent	(eg: 20)
% Silica Fume	0	percent	(eg: 8)
Concrete Protection	DCI / Rheocrete + CNI : 10 l/m ³		
Rebar Protection	DCI / Rheocrete + CNI : 15 l/m ³ DCI / Rheocrete + CNI : 20 l/m ³ DCI / Rheocrete + CNI : 25 l/m ³ DCI / Rheocrete + CNI : 30 l/m ³		
Barrier	Rheocrete 222+ : 5 l/m ³		

Buttons at the bottom: OK, Cancel, Apply.

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Modelo de Predição de Vida Útil (Criando Argumentos para Analise.....)



Scenarios Definition

Automatic Definition | **User Defined**

Scenario List

Name: Base Case

Defined Types

Add: Base Case

Modify

Delete

Scenario Definition

Concrete Cost: 100.00 \$/m³ (eg: 100.00)

W/C Ratio: 0.42 (eg: 0.35)

% Class F Fly Ash: 0 percent (eg: 20)

% Slag: 0 percent (eg: 20)

% Silica Fume: 0 percent (eg: 8)

Concrete Protection: Calcium Nitrite Inhibitor: 10 l/m³

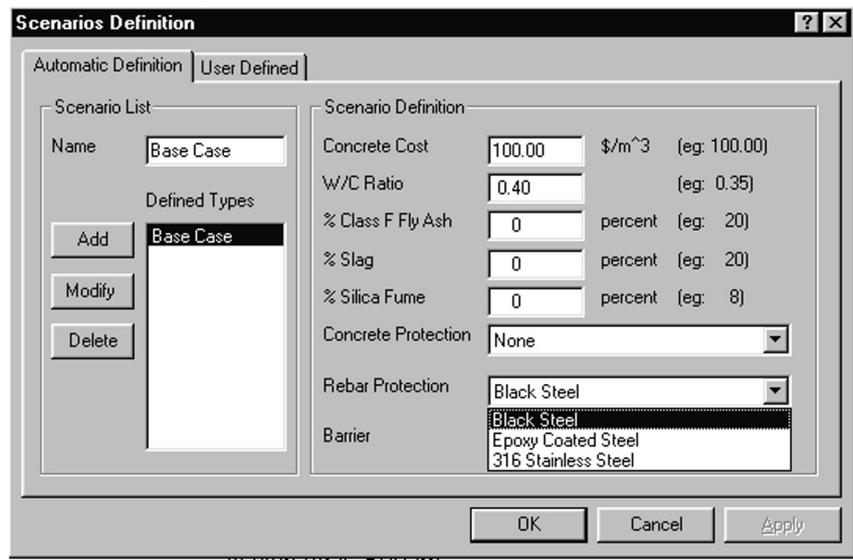
Rebar Protection: Calcium Nitrite Inhibitor: 15 l/m³
Calcium Nitrite Inhibitor: 20 l/m³
Calcium Nitrite Inhibitor: 25 l/m³
Calcium Nitrite Inhibitor: 30 l/m³

Barrier: Amines & Esters: 5 l/m³

OK Cancel Apply

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Modelo de Predição de Vida Útil (Criando Argumentos para Analise.....)



Scenarios Definition

Automatic Definition | **User Defined**

Scenario List

Name: Base Case

Defined Types

Add: Base Case

Modify

Delete

Scenario Definition

Concrete Cost: 100.00 \$/m³ (eg: 100.00)

W/C Ratio: 0.40 (eg: 0.35)

% Class F Fly Ash: 0 percent (eg: 20)

% Slag: 0 percent (eg: 20)

% Silica Fume: 0 percent (eg: 8)

Concrete Protection: None

Rebar Protection: Black Steel

Barrier: Black Steel
Epoxy Coated Steel
316 Stainless Steel

OK Cancel Apply

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Modelo de Predição de Vida Útil (Criando Argumentos para Análise.....)

The screenshot shows the 'Scenarios Definition' dialog box with the 'User Defined' tab selected. The 'Scenario List' on the left contains 'Base Case'. The 'Scenario Definition' on the right is configured as follows:

Parameter	Value	Unit	Example
Concrete Cost	100.00	\$/m ³	(eg: 100.00)
W/C Ratio	0.42		(eg: 0.35)
% Class F Fly Ash	0	percent	(eg: 20)
% Slag	0	percent	(eg: 20)
% Silica Fume	0	percent	(eg: 8)
Concrete Protection	Calcium Nitrite Inhibitor : 10 l/m ³		
Rebar Protection	Black Steel		
Barrier	None		

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Modelo de Predição de Vida Útil (Criando Argumentos para Análise.....)

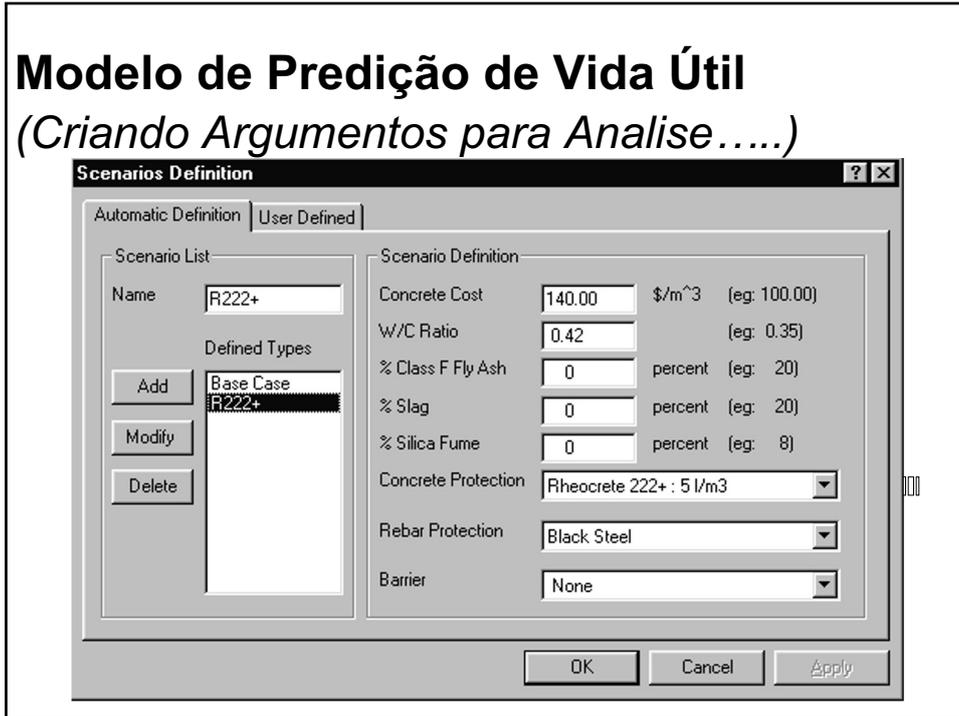
The screenshot shows the 'Scenarios Definition' dialog box with the 'User Defined' tab selected. The 'Scenario List' on the left contains 'Base Case' and 'CNI'. The 'Scenario Definition' on the right is configured as follows:

Parameter	Value	Unit	Example
Concrete Cost	140.00	\$/m ³	(eg: 100.00)
W/C Ratio	0.40		(eg: 0.35)
% Class F Fly Ash	0	percent	(eg: 20)
% Slag	0	percent	(eg: 20)
% Silica Fume	0	percent	(eg: 8)
Concrete Protection	Calcium Nitrite Inhibitor : 20 l/m ³		
Rebar Protection	Black Steel		
Barrier	None		

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Modelo de Predição de Vida Útil

(Criando Argumentos para Analise.....)



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Modelo de Predição de Vida Útil

Description of Structure

Design Life = 75 years
Discount Rate = 3.0 %
Repairs every 10.0 years to 10.0 %
of slab for \$ 500 /m²

Properties of Scenarios

Base Case Mix Design : w/c = 0.40, Cost 100 \$/m³
D₂₈ = 7.94x10⁻¹² m²/s , m = 0.20 , C_t = 1.16 kg/m³
Black Steel (0.66 \$/kg) , Propagate = 6 years

CNI Mix Design : w/c = 0.40, Cost 100 \$/m³
D₂₈ = 7.94x10⁻¹² m²/s , m = 0.20 , C_t = 7.36 kg/m³
Black Steel (0.66 \$/kg) , Propagate = 6 years
Calcium Nitrite Inhibitor : 20 l/m³

Surface History (Total)

Annual Temp. History

Port of Project
L365 SLP Engineers 2000/5/24

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Modelo de Predição de Vida Útil (Resumo dos Dados)

Base Case Mix Design : w/c = 0.40, Cost 100 \$/m³
 $D_{28} = 7.94 \times 10^{-12} \text{ m}^2/\text{s}$, m = 0.20 , $C_t = 1.16 \text{ kg/m}^3$
 Black Steel (0.66 \$/kg) , Propagate = 6 years

CNI Mix Design : w/c = 0.40, Cost 100 \$/m³
 $D_{28} = 7.94 \times 10^{-12} \text{ m}^2/\text{s}$, m = 0.20 , $C_t = 7.36 \text{ kg/m}^3$
 Black Steel (0.66 \$/kg) , Propagate = 6 years
 Calcium Nitrite Inhibitor : 20 l/m³

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Modelo de Predição de Vida Útil (Definição do Usuário)

Scenarios Definition

Automatic Definition | **User Defined**

Scenario List

Name: System "x"

Defined Types

Add

Modify

Delete

Scenario Details

Cost: \$/yd³ (eg. 100.00)

Diffusion coefficient: m²/s (eg. 1.00e-11)

m term: (eg. 0.10)

Corrosion Threshold: lb/yd³ (eg. 0.05)

Propagation Time: years (eg. 6)

OK Cancel Apply

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Modelo de Predição de Vida Útil (Resumo dos Parâmetros de Dados)

- ✓ Coeficiente Aparente de Difusão de Cloretos, D_{28}
- ✓ Coeficiente de Redução de Difusão, m
- ✓ Máximo Conteúdo de Cloreto na Superfície, C_{max}
- ✓ Taxa de Acúmulo de Cloreto na Superfície, k
- ✓ Limite de Cloreto para Início da Corrosão, C_t
- ✓ Cobrimento da Armadura, x

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Modelo de Predição de Vida Útil (Informação dos Detalhes de Reparos)

Detailed Repair Information

Detailed Properties

Scenarios

Name: Base Case

Defined Types

Add

Modify

Delete

Base Case

CNI

Repair Definition

Repair Cost: 400.00 \$/m² (eg: 500.00)

Repair Interval: 10.0 years (eg: 0.1)

Repair Area: 10 percent (eg: 10)

OK Cancel Apply

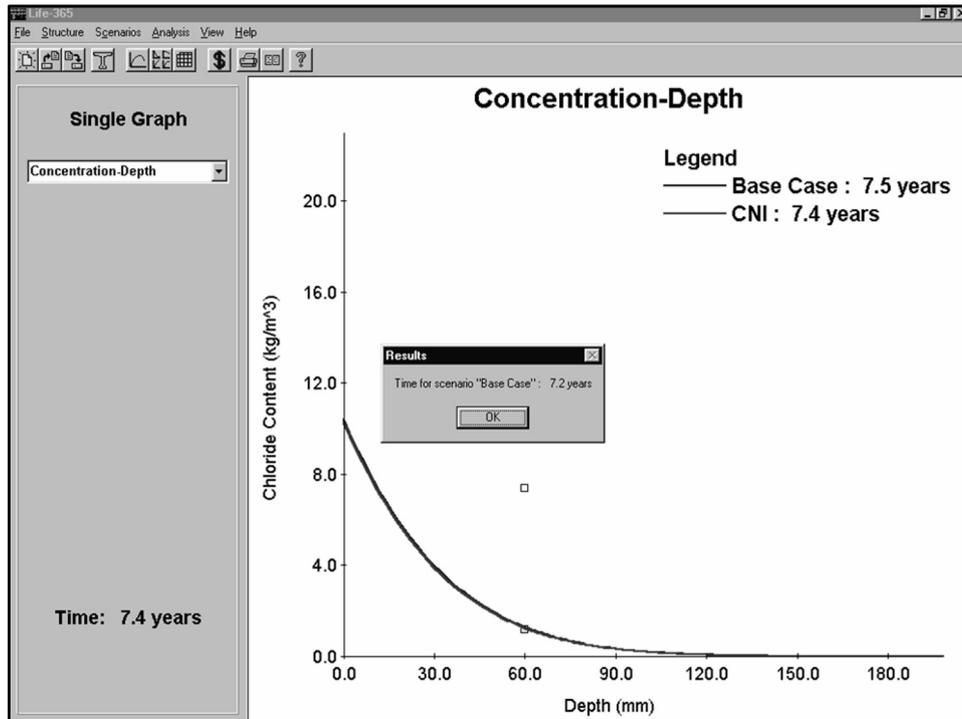
53

Análise do Custo do Ciclo de Vida (Resumo dos Parâmetros de Dados)

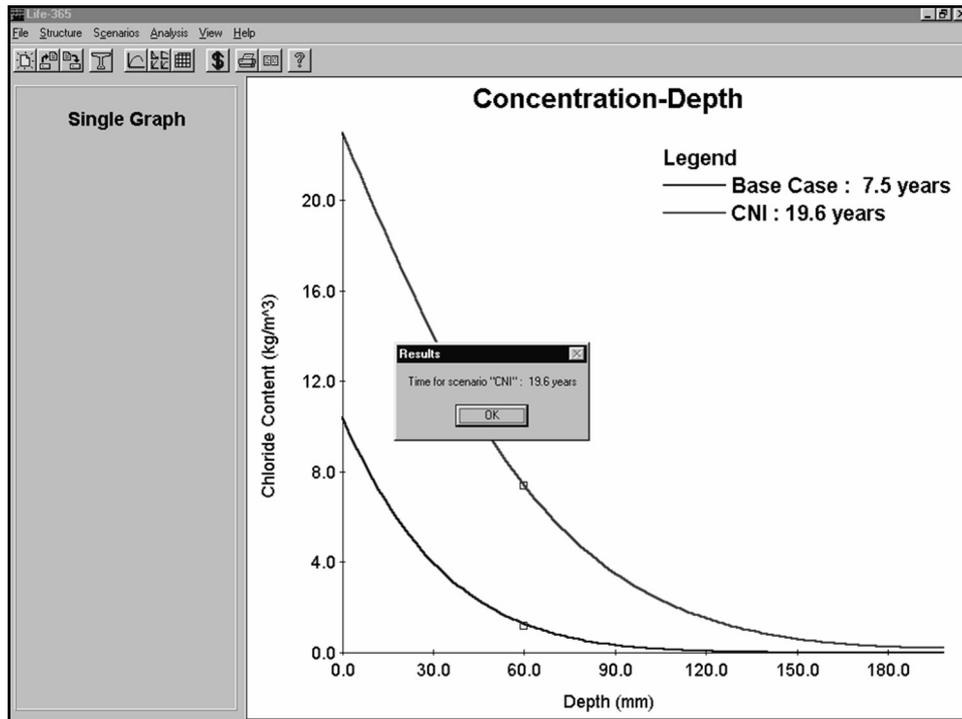
- ✓ **Custo do Concreto Armado, Armadura, Selador / Membrana**
 - ✓ **Custo dos Reparos**
 - ✓ **Taxa de Juros, i**
- Custo Futuro de Reparos (F)
no tempo (t)
calculado no
"Valor Presente" (PW) base

$$PW = \frac{F}{(1+i)^t}$$

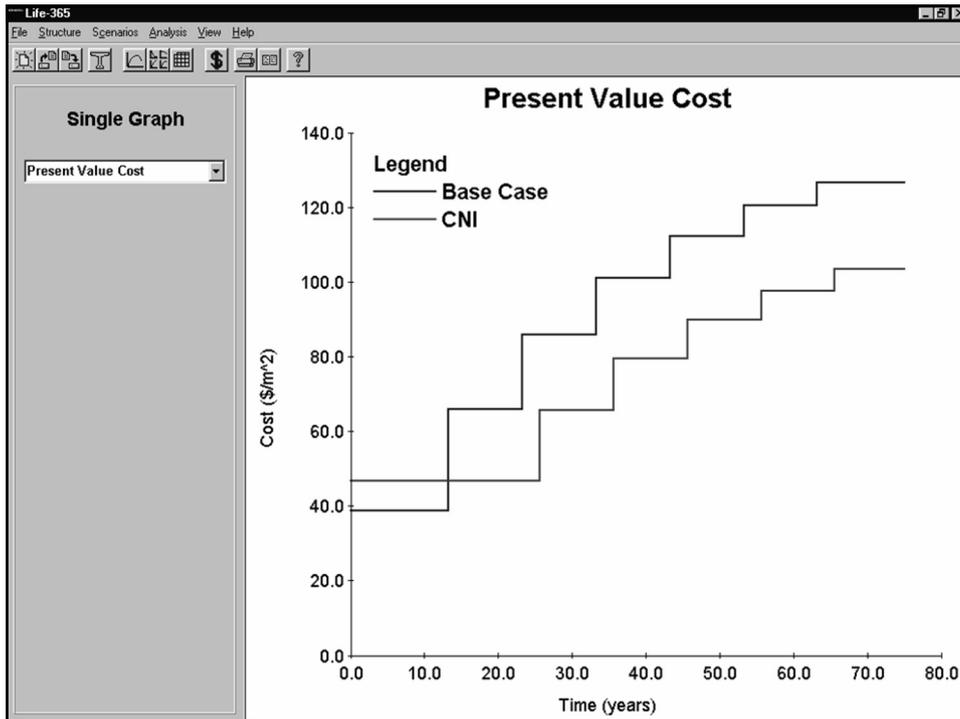
54



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Project Title: Port of Project Date: 2000/8/10 - 11:01 am
 Performed by: SLP Engineers

Structure: 1D slab/wall structure Exposure: Marine Spray Zone
 Location: SAN JUAN , Puerto Rico 23.00 kg/m³ @ 17 years
 Clear cover: 60 mm

Design Life: 75 years Discount Rate: 3.0 %

Scenario Name	Initial Cost (\$/m ²)	Repair Cost (\$/m ²)	Repair Area (%)	Repair Interval (years)	Time to Initiation (years)	Time to 1 st Repair (years)	Total Life Cycle Cost (\$/m ²)
CNI	46.84	400.00	10	10	19.6	25.6	103.52
Base Case	38.84	400.00	10	10	7.2	13.2	126.72

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Modelo de Predição de Vida Útil (Informações Detalhadas do Reparo)

Detailed Repair Information

Detailed Properties

Scenarios

Name:

Defined Types

Add

Modify

Delete

Repair Definition

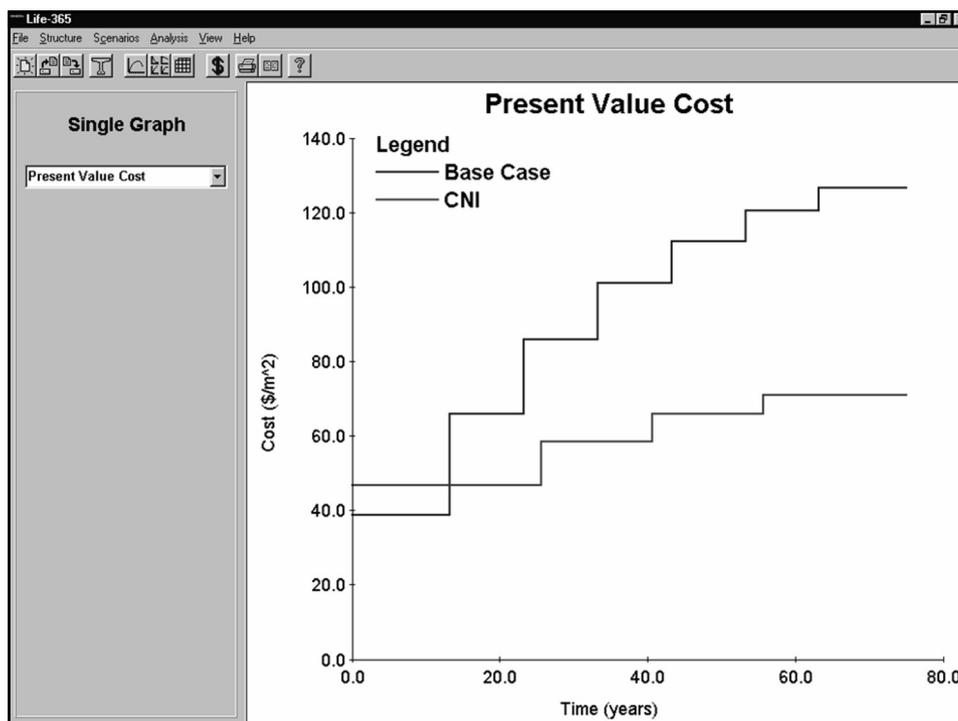
Repair Cost: \$/m² (eg: 500.00)

Repair Interval: years (eg: 0.1)

Repair Area: percent (eg: 10)

OK Cancel Apply

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Life-365

File Structure Scenarios Analysis View Help

Single Graph

Tabular Output

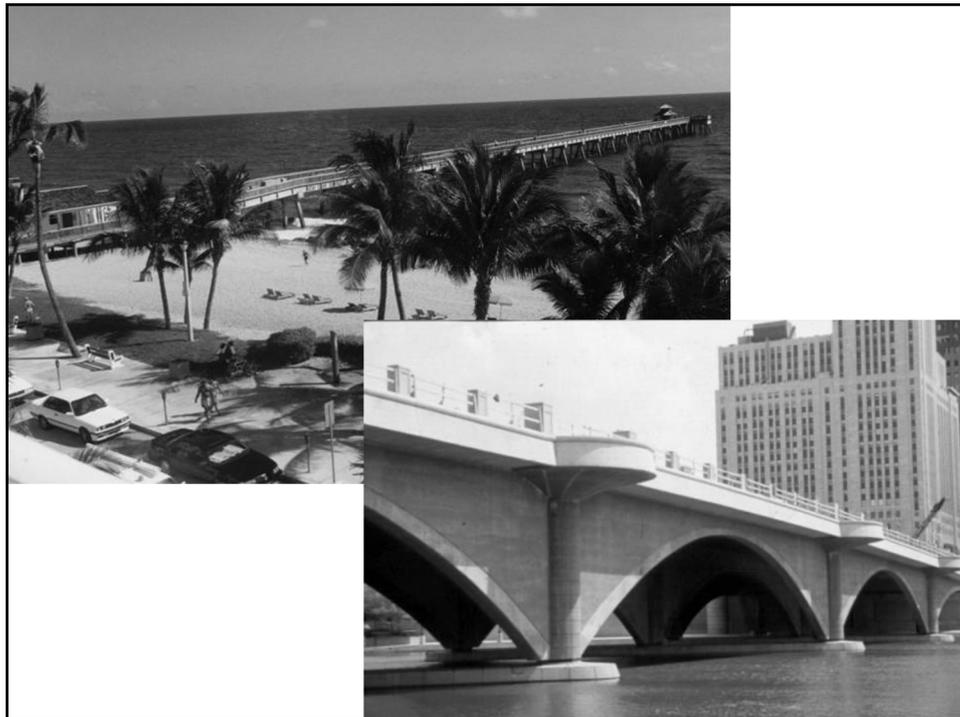
Project Title: Port of Project Date: 2000/8/10 - 11:25 am
 Performed by: SLP Engineers

Structure: 1D slab/wall structure Exposure: Marine Spray Zone
 Location: SAN JUAN , Puerto Rico 23.00 kg/m³ @ 17 years
 Clear cover: 80 mm

Design Life: 75 years Discount Rate: 3.0 %

Scenario Name	Initial Cost (\$/m ²)	Repair Cost (\$/m ²)	Repair Area (%)	Repair Interval (years)	Time to Initiation (years)	Time to 1 st Repair (years)	Total Life Cycle Cost (\$/m ²)
CNI	46.84	250.00	10	15	19.6	25.6	70.96
Base Case	38.84	400.00	10	10	7.2	13.2	126.72

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