The Application of Fuzzy Modeling to Hazard Assessment for Reinforced Concrete Building Structures Due to Pipeline Failure

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Abstract: In this article, the application of fuzzy modeling to hazard assessment for reinforced concrete building structures due to pipeline failure was implemented. Damage assessment due to sewer pipeline failure is a very important issue in urban regions in Egypt. By combining ground deformation patterns, well-known damage category criteria, the potential damage of adjacent buildings can be assessed due to different parameters of pipeline deterioration. In this study, the well-known computer program ANSYS with geotechnical module "CivilFEM" is used considering nonlinear elastic soil behavior. The finite element model is chosen to investigate the influence of four different parameters of pipeline deterioration at the same time such as pipeline settlement, settlement location, building location with respect to pipeline and burial depth on the building damage category. The results were implemented in a fuzzy based assessment system for reinforced concrete building structures to evaluate the damage category of building. A criterion to define membership functions for each parameter, as input to the fuzzy engine, as well as the rule base was described. The fuzzy output as damage category was briefly validated by using numerous examples for different values that was chosen randomly to cover the whole range of 4 parameters to get the results first in fuzzy system, then running the same values using ANSYS and results were consistent in the two methods. Fuzzy logic support system showed to be a powerful tool in forecasting potential damage in buildings due to the association of different parameters in pipeline deterioration.

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1. Introduction

In a major developing country like Egypt the problem of sewer pipeline deterioration draws much attention. Therefore, the influence of pipeline failure on adjacent structures is very important to investigate.

A finite element computer program "ANSYS+CivilFEM"[1], was employed to perform the analysis and investigate the general failure mechanisms of soil- structure interaction. This analysis produced a large amount of output data[7]. The pipeline failure can induce vertical settlement of the foundation of the adjacent structure, which results in noticeable damage of buildings. The report by Aye [2] was used as a basic reference in ground deformation prediction and building damage assessment. For cut-and-cover excavation zone, the work of **Peck** [3], **Clough** [4] was used whereas published papers of **Burland** [5], **Boscardin and Cording** [6] were applied for bored tunnels. Also, **Metwally** [7] has evaluated the damage assessment of building due to deterioration of pipelines. This was the base of our previous work by Emarah *et al* [18] that was extended in this research. The damage categories are based directly on the descriptions of damage provided in Table 1.

The calculation of damage category by "ANSYS+CivilFEM" software is time consuming and it doesn't cover the entire operation range. Therefore, an expert system will be implemented to predict the degree of damage for different parameters of pipeline failure.

One of the most important applications of expert systems in engineering is fuzzy logic. The fuzzy set theory was developed by **Lofty Zadeh** [8] in 1965 to deal with imprecise and uncertain phenomena often presented in real-world applications. It provides[9]a powerful tool to model uncertainty associated with lack of information.

Consequently, fuzzy logic provides an efficient way of handling the uncertainty for complex systems without sufficient data or only with vague information [10,11]. The fuzzy controller has been used [12] for optimization of the active control of civil engineering structures [13-17]. The main advantages of the fuzzy controller are [14]:

- It is one of the few mathematical model free approaches to system identification and control which makes the system easier to design than developing an accurate mathematical model of the structural system needed for control system design. This can be done by using human experience and expertise to implement the fuzzy controller.
- The fuzzy controller can be adaptive by modifying its rules or membership functions and employing learning techniques.

In this study, a fuzzy rule-based decision support system is developed to determine the damage category of a building for a wide range of different parameters, depending on differential settlement underneath the building crack width and number of cracks obtained from ANSYS model. This was accomplished for two different parameters [18] and will be extended in this study for four parameters.

Table 1 Building damage classification after Burland [5] and Boscarding and Cording [6].

Risk Category	Degree of Damage	Description of Typical Damage	Approximate Crack Width (mm)
0	Negligible	Hairline cracks	Null
1	Very Slight	Fine cracks easily treated during normal decoration	0.1 to 1
2	Slight	Cracks easily filled. Several slight fractures inside building. Exterior cracks visible	1 to 5
3	Moderate	Cracks may require cutting out and patching. Door and windows sticking	5 to 15 or a number of cracks > 3
4	Severe	Extensive repair involving removal and replacement of walls, especially over doors and windows. Windows and door frames distorted. Floor slopes noticeably.	15 to 25 but also depends on number of cracks
5	Very Severe	Major repair required involving partial or complete reconstruction. Danger of instability.	> 25 but depends on number of cracks

2. Fuzzy inference systems

Fuzzy logic [9] is a kind of multi-valued logic utilizing fuzzy sets to perform approximate reasoning. Additionally, a fuzzy rule-based system is a methodology for the interpretation of natural language, which is essential for linguistic expressions. Fuzzy rules and fuzzy reasoning are the fundamentals of fuzzy inference processes that are utilized to derive meaningful conclusions from ambiguous information [11].

In this context, Fuzzy Inference Systems (FIS), also known as fuzzy rule-based systems, are well-known tools for the simulation of nonlinear behaviors with the help of fuzzy logic and linguistic fuzzy rules. There are currently several popular inference techniques developed for fuzzy systems, such as **Mamdani and Assilian** [19], and **Takagi and Sugeno** [20]. Mamdani FIS was selected to be used in this study. In the Mamdani FIS, inputs and outputs are represented by fuzzy relational equations in a canonical rule based form. These linguistic IF-THEN rules are associated with logical connectives, namely AND, OR, ELSE.

Another important point that should be explained about fuzzy rule-based systems is how the aggregation of fuzzy rules is performed. It is necessary to obtain an overall conclusion through a consideration of results from each rule. The combination of entire outcomes in a rule-base is referred as the aggregation of fuzzy rules. Similar to the association of fuzzy variables, there are two cases used in the aggregation process, namely conjunctive and disjunctive systems of rules [10-11]. A graphical representation of a Mamdani inference system with two rules and two crisp inputs is shown in Figure 1.But it is necessary to obtain a single value instead of a region to reach a decision; therefore, the solution should be defuzzified to get a crisp outcome. The centroid defuzzification method was chosen in this research.

3. Description of basic model

Figures 2 and 3 depict the full three-dimensional geometry model which was used to quantify the interaction between sewer pipeline and the reinforced concrete building with masonry in-fill walls in the coupled analysis. The assumed values in this parametric study are deduced from the practical observations of the deteriorated sewer pipes within the Greater Cairo sewer network[7]. The pipeline comprises 20 pipe segments, where the connections between them are contact element. The type of contact element of pipes connection was taken as “no separation contact element”. In this “no separation contact" element, the two contact surfaces "target and contact surfaces" are tied, although sliding is permitted. The pipeline is encased in a homogeneous, continuous, and isotropic soil mass. In addition, frictional slip is allowed between pipe and soil. The used data are shown in Table 2. The column's spacing of building in the two directions s = 5.0 m, and height of each level h = 3.0 m. The properties of structural materials taken for deformation and failure prediction calculations are shown in Table 3. The contact element between the foundation of the building and the soil was taken rough element. In this element (rough contact), the two contact surfaces (target and contact surfaces) are not slipping, although separation is permitted.

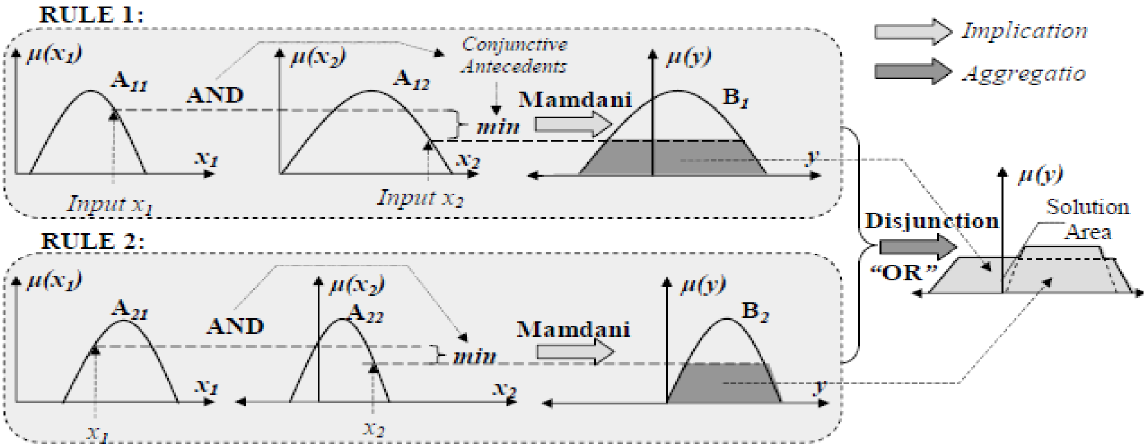


Figure 1 Graphical illustration of Mamdani inference methodology (2 rules and 2 inputs) [9].

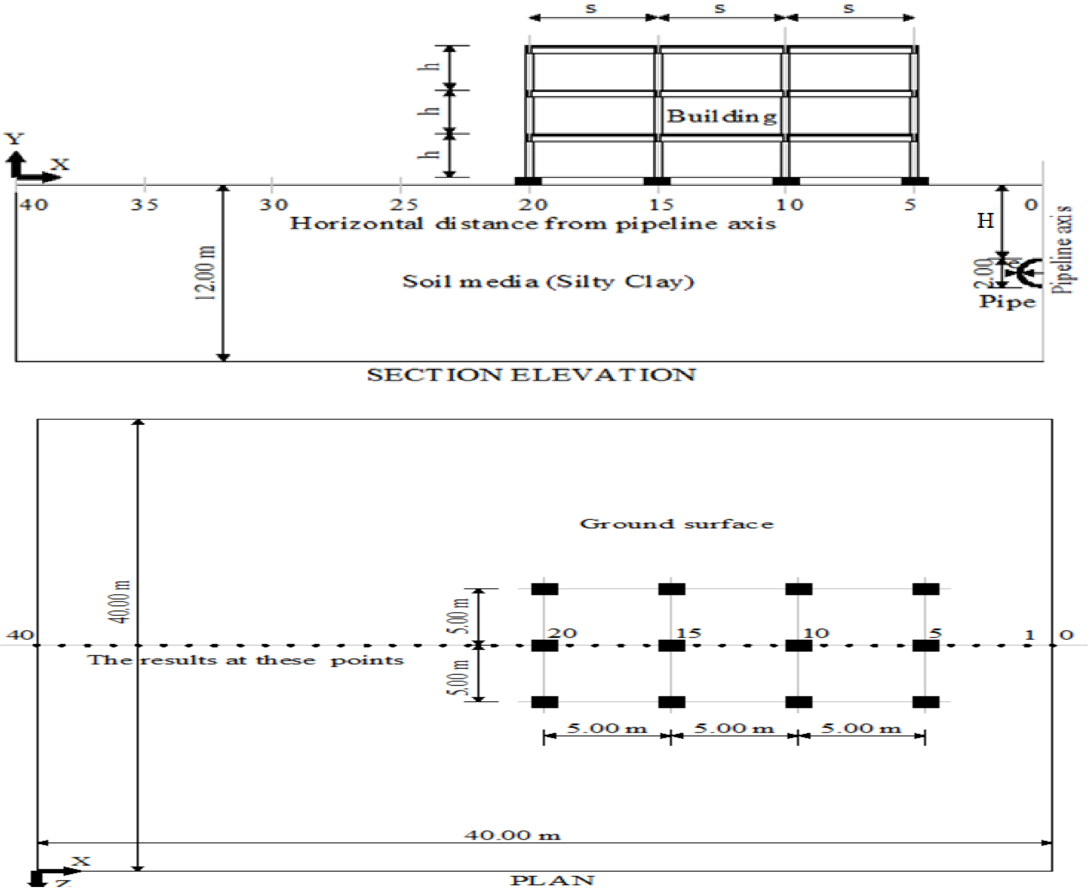


Figure 2 Geometric model.[18]

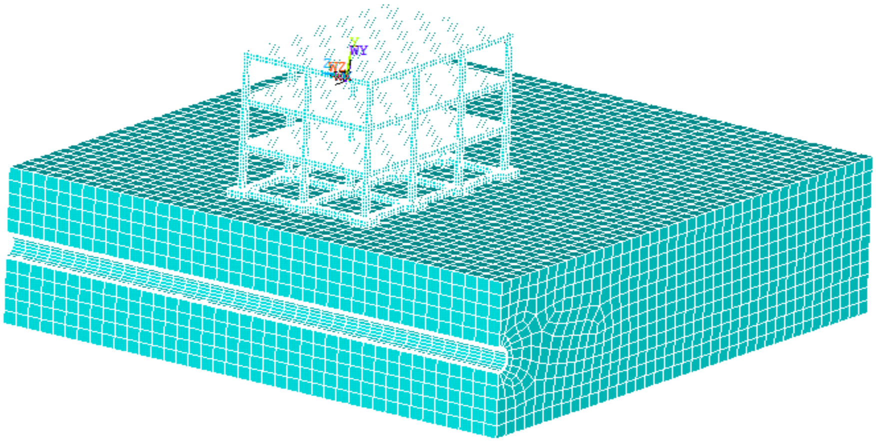


Figure 3 FEM model.[18]

Table 2 Soil and pipeline properties [7].

Soil properties		Pipeline properties	
Soil elastic modulus E_s	2000 t/m^2	Pipe diameter D (interior)	2.00 m
Soil Poisson's ratio υ	0.35	Wall thickness of concrete e	0.20 m
Soil cohesion C	2.00 t/m^2	Pipe length Lp	2.00 m
Angle of internal friction ϕ	30^o	Number of pipes in pipeline	20 pipes
Density of soil over pipe γ	1.85 t/m^3	Concrete elastic modulus E_c	3.5E6 t/m^2
Soil height above crown H_t	5.0 m	Concrete Poisson's ratio υ_c	0.20
μ (Between soil& pipes)	0.32	μ (Between pipes segments)	0.60

Table 3 Structural material data [7].

Properties	Notation & Unit	Building elements
Density	γ (t/m^3)	2.5
Compressive stress*	f_c (kg/cm^2)	90
Tensile stress*	ft (kg/cm^2)	10.8
Shear stress*	q (kg/cm^2)	19
Young's modulus	E (t/m^2)	2.1E06
Poisson's ratio	N	0.20
compressive strain*	ε_c	0.003
tensile strain*	ε_t	0.003
Shear strain*	ε_s	0.003

*Allowable stress or strain

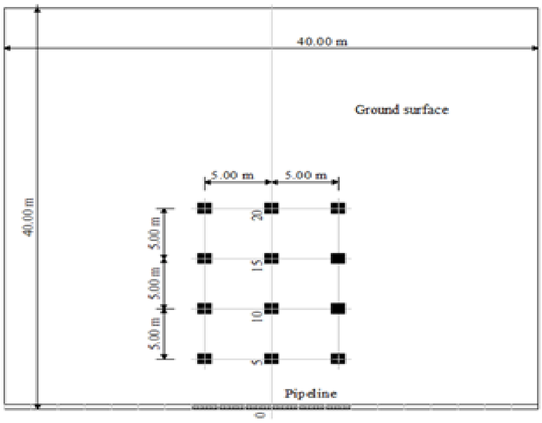
4. Inputs of fuzzy logic

The damaging impact of pipeline settlement on building performance has been shown to be a major problem for urban areas due to high reconstruction and maintenance costs. The assumptions of parametric study of this part are deduced from the practical observations of the deteriorated sewer pipes within the Greater Cairo sewer network [7].

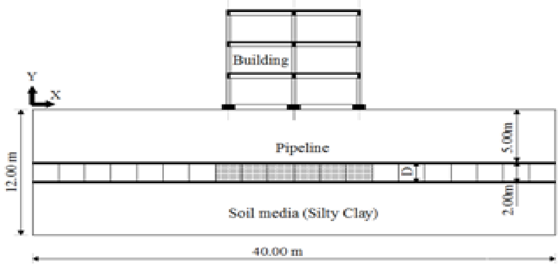
4.1 Effect of pipeline settlement on building

The influence of settlement in the pipelines is explained by considering three values of vertical settlement in the middle six pipe segments; 1% D, 3% D, and 5% D, where D is the pipe diameter as shown in Fig. 4. Figure 5 shows the relation between the vertical settlement of building and the pipeline settlement. It is apparent that increasing the vertical settlement of pipeline leads to the increase of the deformations of the adjacent building.

Table 4 illustrates the results for evaluating the potential damage category for building due to different values of pipeline settlement. The results presented in this table show the values of differential settlement, tilting angle α for the base of building and illustrate the influence of pipeline settlement on the value of crack width. We can find out that, the maximum building deformation and damage at the maximum pipeline settlement. It is clear that the value of pipeline settlement plays an important role in building deformation and damage.



(a) Plan



(b) Elevation

Figure 4 Location of pipeline settlement.[18]

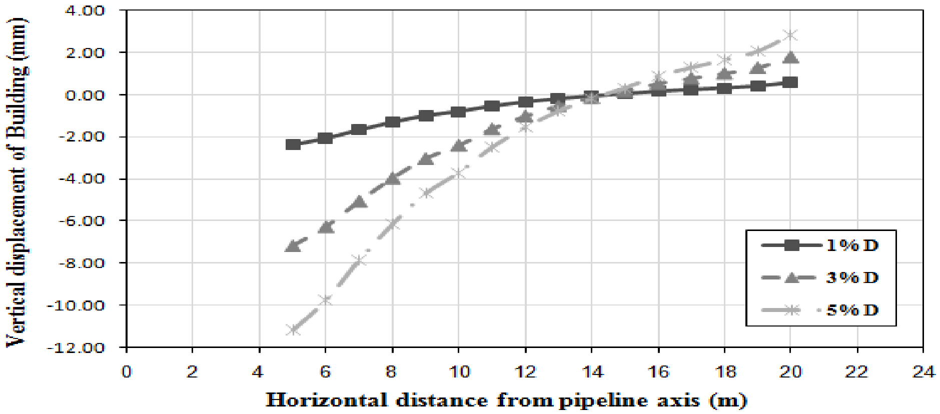


Figure 5 Effect of pipeline settlement on vertical settlement of building.[18]

Table 4 Evaluation of potential damage in building due to pipeline settlement.[18]

Properties	Case		
	1% D	3% D	5% D
Differential Sett.(ΔS)mm	2.94	8.93	14.04
Angle of Tilt (α) rad.	0.00020	0.00060	0.00094
Cumulative Maximum Tensile Crack Width (C_t) mm	0.88	2.80	4.79
Cumulative Maximum Principal Crack Width (C_p) mm	0.81	2.50	4.06
Damage Category	Very Slight	Slight	Moderate

4.2 Effect of settlement location on building

The influence of settlement location relative to the building in the pipelines is explained by considering three different horizontal locations of settlements as shown in Fig. 6. At case 1, the centerline of six pipe segments at the centerline of building (X =0.00m). At case 2, the start of six pipe segments at X=6.00m from centerline of building. At case 3, the start of six pipe segments at X=12.00m from centerline of building. The pipeline settlement value was taken 5% D where D is pipe diameter.

The influence of the settlement location on the vertical settlement of building is shown in Fig. 7. As seen, the vertical settlement of building decreases with increasing the distance to the location of pipeline settlement.

Table 5 illustrates the results for evaluating the potential damage category for building due to the location of settlement in the pipeline. The results presented in this table show the values of differential settlement, tilting angle α for the base of building, and illustrate the influence of pipeline settlement location on the value of crack width. We can find out that, the maximum results of building deformation and damage are for the nearest location of pipeline settlement (X=0.00m).

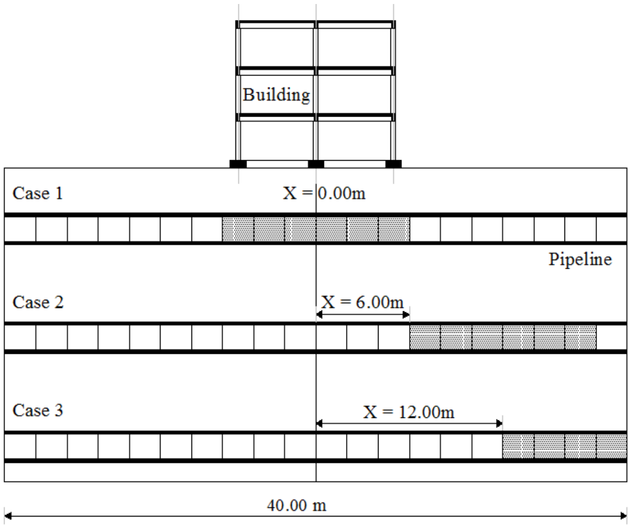


Figure 6 Location of vertical settlement of pipeline.

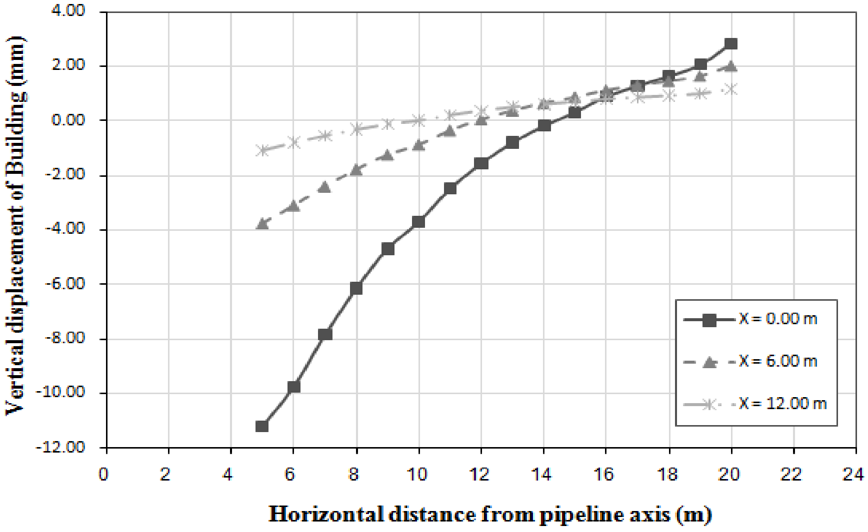


Figure 7 Effect of pipeline settlement location on vertical settlement of building.

Table 5 Evaluation of potential damage in building due to the location of pipeline settlement.

Properties	Case		
	X =0.00m	X =6.00m	X =12.00m
Differential Sett.(ΔS)mm	14.04	5.79	2.23
Angle of Tilt (α) rad.	0.00094	0.00039	0.00015
Cumulative Maximum Tensile Crack Width (C_t) mm	4.79	1.39	0.56
Cumulative Maximum principal Crack Width (C_p) mm	4.06	1.37	0.52
Damage Category	Moderate	Slight	Very Slight

4.3 Effect of burial depth on building

The influence of burial depth is demonstrated by considering three heights of soil above the crown of the pipe; 3, 5, and 7 m. Tables 2 and 3 give the properties of silty clay soil, pipe, and building respectively. The settlement value was fixed as 5% D (D is pipe diameter) in the middle 6 pipe segments. Figure 8 illustrates the influence of burial depth and pipeline settlement on the vertical settlement of building. We can notice that increasing the height of soil above the pipe decreases the building deformations.

Table 6 illustrates the results for evaluating the potential damage category for building due to settlement in pipeline and different burial depth. The results presented in this table show the values of differential settlement, tilting angle α for the base of building and illustrate the influence of different burial depth with settlement in pipeline on the value of crack width. We can find out that, the building damage is increasing by decreasing in the soil height above pipeline.

4.4 Effect of building location on building

The influence of building location relative to pipeline settlement is demonstrated by considering three different locations from the nearest side of building relative to the centerline of the pipeline (XB); 3, 5, and 7 m as shown in Fig. 9. The settlement value was taken 5% D (D is pipe diameter) in six pipe segments at (X=0.00m) as shown in Fig. 6. In case 1 the tensile and principal crakes are calculated at the first bay from (3m to 8m). In case 3 the tensile and principal crakes are calculated at the first bay from (7m to 12m).

The influence of the building location and pipeline settlement on the vertical settlement of building is shown in Fig. 10. As seen, the maximum numerical results obtained from the position of the nearest location (XB=3.00m) of the building to the pipeline.

Table 7 illustrates the results for evaluating the potential damage category for building due to building location and pipeline settlement. The results presented in this table show the values of differential settlement, tilting angle α for the base of building, significant difference for building damage for the all building locations relative to the pipeline settlement.

5. Damage evaluation of building using fuzzy logic tool

One of the most important applications of fuzzy logic is that it can be used for decision process based on available data and knowledge. This study aims to construct a decision support system for damage category of reinforced concrete building structures based on numerical solutions obtained from ANSYS results for a wide range of parameters. Four different variables that have influence on building damage were used as inputs for fuzzy system. Then a procedure using the fuzzy inference methodology was developed to determine the output of a fuzzy system. The global structure of FIS component is depicted in Fig. 11. The shape of membership functions is chosen by trial and error to get the best representation of each input and output parameters.

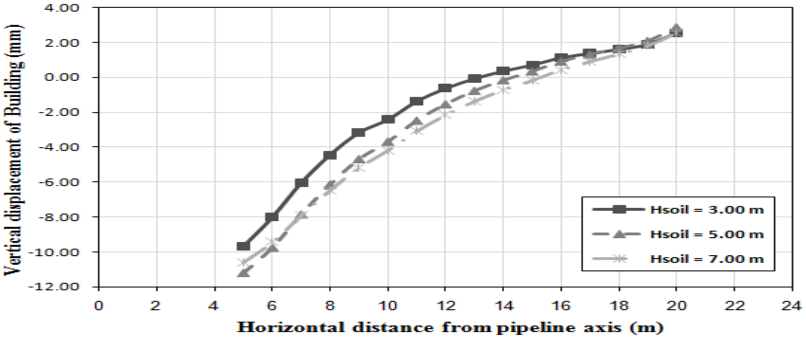


Figure 8 Effect of burial depth on vertical settlement of building. [18]

Table 6 Evaluation of potential damage in building due to the burial depth value.[18]

Properties	Case		
	$H_{soil} = 3m$	$H_{soil} = 5m$	$H_{soil} = 7m$
Differential Sett.(ΔS)mm	12.25	14.04	13.14
Angle of Tilt (α) rad.	0.00082	0.00094	0.00088
Cumulative Maximum Tensile Crack Width (C_t) mm	5.98	4.79	2.82
Cumulative Maximum Principal Crack Width (C_p) mm	4.55	4.06	2.92
Damage Category	Moderate	Moderate	Slight

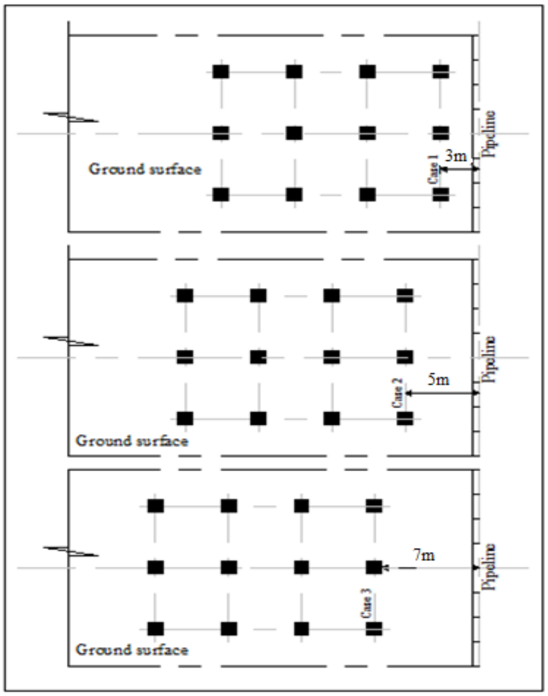


Figure 9 Different building location.

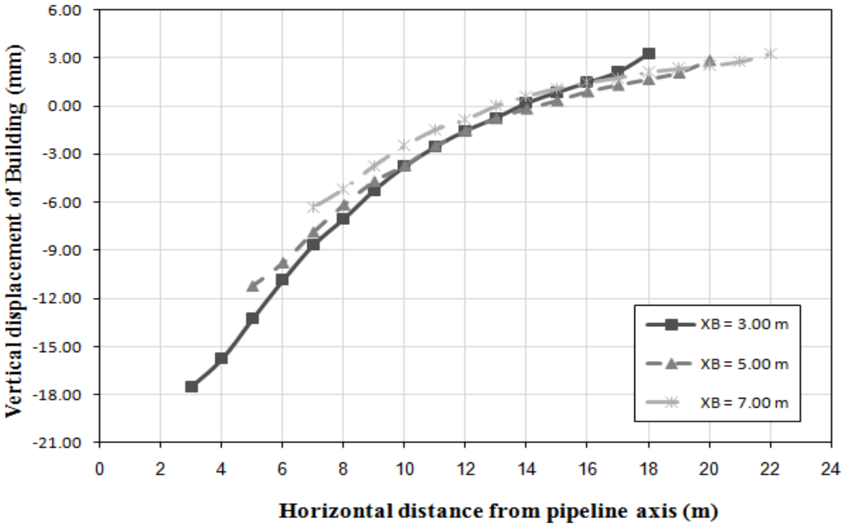


Figure 10 Effect of building location on vertical settlement of building.

Table 7 Evaluation of potential damage due to building location from pipeline settlement.

Properties	Case		
	XB=3.00m	XB=5.00m	XB=7.00m
Differential Sett.(ΔS)mm	20.72	14.04	9.59
Angle of Tilt (α) rad.	0.00138	0.00094	0.00064
Cumulative Maximum Tensile Crack Width (C_t) mm	4.45	4.79	4.47
Cumulative Maximum Principal Crack Width (C_p) mm	4.82	4.06	3.38
Damage Category	Moderate	Moderate	Moderate

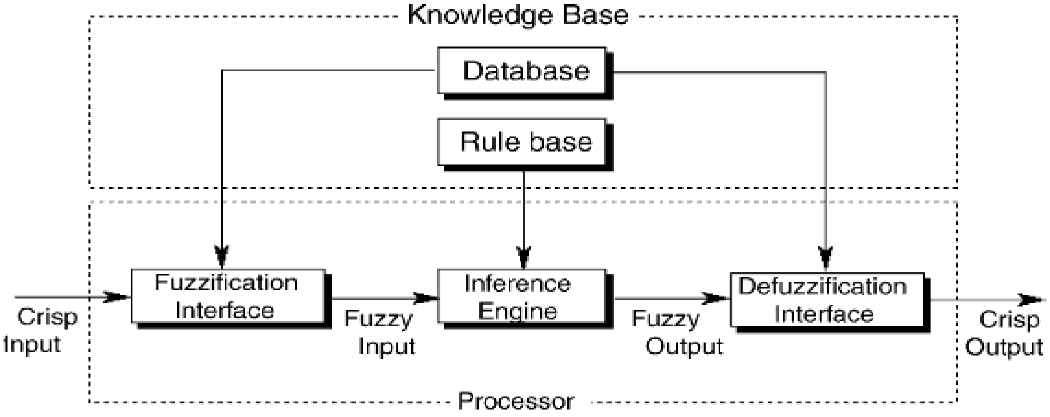


Figure 11 Fuzzy inference systems (FIS) component.

5.1 Four inputs – one output decision support tool

Fuzzy logic decision support tools (FLDST), is a control law that is described by a knowledge-based system consisting of IF . . . THEN rules with vague predicates and a fuzzy inference mechanism. The rule-base is the main part of the FLDST. It is formed by a family of logical rules that describes the relationship between the four inputs (in our case): pipeline settlement along with pipeline settlement location, building location with burial depth and the one output of the fuzzy system (damage category of building).

Based on the operator experience, the structure of the FLDST has four inputs and one output. The fuzzification and defuzzification processes are illustrated as following:

(a) Fuzzification:

Figure 12 illustrates the proposed structure of the FLDST. These inputs are the Pipeline Settlement (P.St), the Settlement Location (St.L.x), Building Location (B.L) and Burial Depth (B.D). The data obtained from ANSYS as shown at Fig. 5 describes the influence of pipeline settlement on the vertical settlement of building. The inputs of this case are the Pipeline Settlement (P.St), the Settlement Location (St.L.x) and the Building Location (B.L). The data obtained from ANSYS describes the influence of pipeline settlement, settlement location and building location on the damage of building.

The universe of discourse for the first input of FLDST is chosen from 1%D to 10%D. Five Membership Functions (MFs) are chosen for the first input (pipeline settlement) where the outer right MF is S function, the outer left is Z function, one of the inner three MFs is a trapezoidal function, and other two are represented by triangle function as shown in Fig. 13.a. The linguistic terms for defining the membership functions are: (1%D), (3%D), (5%D), (8%D) and (10%D), where %D is the percentage of settlement occurs as a function of pipeline diameter.

The data obtained from ANSYS as shown at Fig. 7 describes the influence of pipeline settlement location on the vertical settlement of building. The universe of discourse for the second input (pipeline settlement location) of FLDST is chosen from 0m to 12m. A five membership function are chosen for the second input (settlement location) where the outer right MF is S function, the outer left is Z function, and the inner three MF are represented by triangle function as shown in Fig. 13b. The linguistic variables of MFs defined as (0m), (3m), (6m), (9m), and (12m).

The data obtained from ANSYS as shown at Fig. 10 describe the influence of building location on the vertical settlement of building. The universe of discourse for the third input (building location) of FLDST is chosen from 3m to 7m. Five membership functions are chosen for the third input (building location) where the outer right MF is S function, the outer left is Z function, and the inner three MFs are represented by gaussian function as shown in Fig. 13.c. The linguistic terms for defining the MFs are: (3m), (4m), (5m), (6m), and (7m).

The data obtained from ANSYS as shown at Fig. 8 describe the influence of burial depth on the vertical settlement of building. The universe of discourse for the fourth input (burial depth) of FLDST is chosen from 3m to 7m. Five triangle membership functions are chosen to represent linguistic variables of MF and it's defined as (3m), (4m), (5m), 6m), and (7m) as shown in Fig. 13d.

Finally, six membership functions are used to represent the linguistic variables of output (damage category of building), where the outer right MF is S function, the outer left is Z function, and the inner four MFs are represented by gaussian. The name of six linguistic variables of output are: NEG is negligible, VSL is very slight, SL is slight, MOD is moderate and SV is severe and VSV is very severe as shown in Fig. 13e.

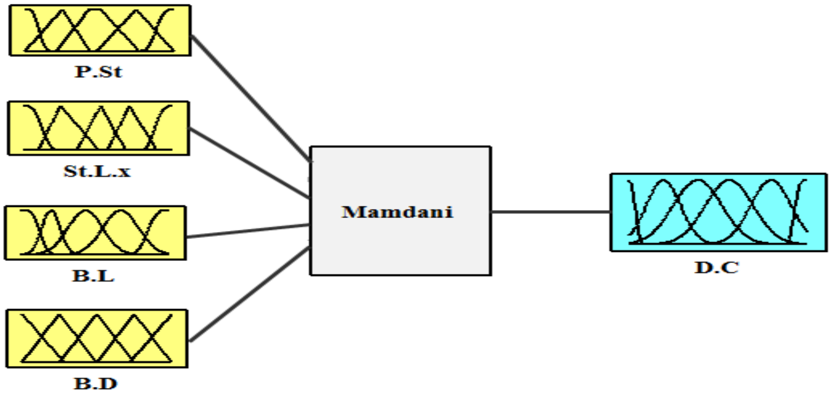


Figure 12 Structure of FLDST: 4 inputs (pipeline settlement, settlement location, building location, burial depth), 1 output (damage category).

(b) Defuzzification:

The rule base was constructed based on data obtained from ANSYS results after solving lots of cases. A sample of these rules that cover the whole range of the four parameters are introduced in Table 8.

Figure 14 illustrates one of the surface of rules in three-dimensions for the four parameters. The damage category is determined for different values of pipeline settlements as well as for different settlement locations at the fixed value of burial depth and building location. It can be shown that the value of settlement has more effect on building damage than settlement location.

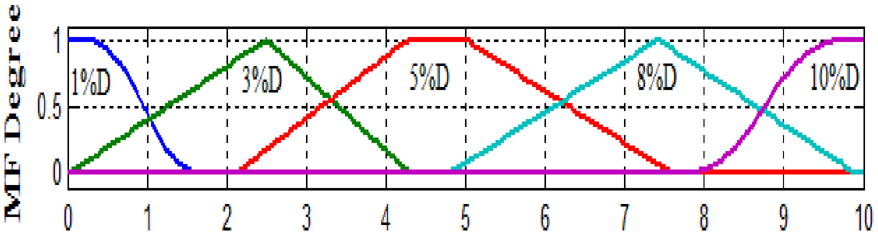
Figure 15 illustrates another surface of rules in three-dimensions for the four parameters. The damage category is determined for different values of pipeline settlements as well as for different value of burial depth at the fixed value of settlement locations and building location. It can be shown that the value of settlement has more effect on building damage than burial depth.

(c)Validation of Results:

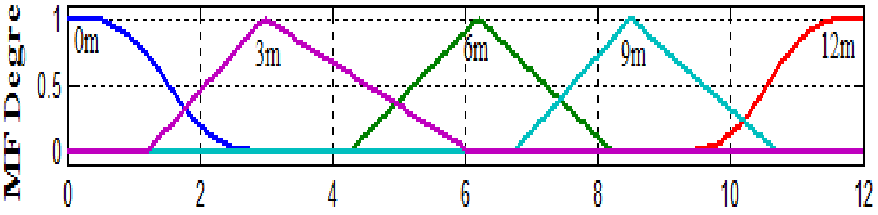
The fuzzy output as damage category was briefly validated by using numerous examples for different values for the four parameters that was chosen randomly to cover the whole range of 4 parameters, as inputs, to get the results first in fuzzy system. Then, running the same values using ANSYS and all the results were consistent in the two methods. Some of these values that were run twice were introduced in the Table 9.

These examples were run by ANSYS for different pipeline settlement along with different pipeline settlement location, different burial depths and different building location. The calculated category of damage was consistent to the results obtained from the proposed method.

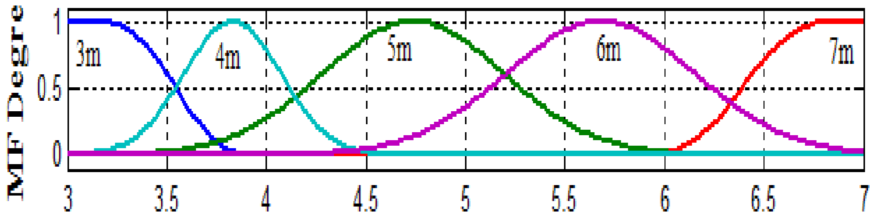
Table 9 illustrates several examples from MATLAB that was validated by ANSYS computer program to validate and evaluate the proposed FLDST in evaluating the damage category of building. FLDST proved to have the ability to cover the entire range of pipeline settlement, settlement location and building location along with burial depth. Now we can use it to evaluate damage category of building at any value of entire range of inputs for accurate results without using ANSYS program and calculations.



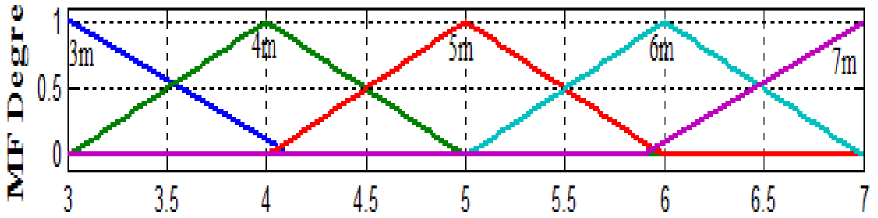
(a) Pipeline settlement (%D)



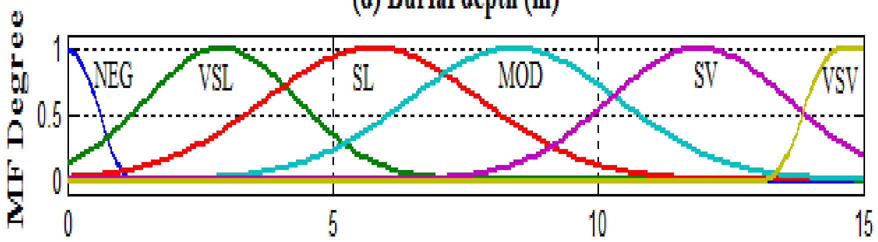
(b) Settlement location (m)



(c) Building location (m)



(d) Burial depth (m)



(e) Damage category

Figure 13 Membership functions inputs (a), (b), (c), (d) and output (e) of FLDST.

Table 8 Fuzzy rule base for four inputs

			Pipeline Settlement (%D)				
XB	H_{soil}	X	1%	3%	5%	8%	10%
Building Location (XB)	Burial Depth (H_{soil})	Settlement Location (X)					
3m	3m	0m	SL	MOD	MOD	SV	SV
3m	3m	6m	SL	MOD	MOD	SV	SV
3m	3m	12m	VSL	SL	SL	MOD	MOD
3m	5m	0m	VSL	SL	MOD	SV	SV
3m	5m	6m	VSL	SL	MOD	MOD	MOD
3m	5m	12m	VSL	VSL	SL	SL	MOD
3m	7m	0m	VSL	SL	SL	MOD	SV
3m	7m	6m	VSL	SL	SL	MOD	MOD
3m	7m	12m	VSL	VSL	VSL	SL	MOD
5m	3m	0m	SL	MOD	MOD	SV	SV
5m	3m	6m	SL	SL	MOD	MOD	SV
5m	3m	12m	VSL	SL	SL	MOD	MOD
5m	5m	0m	VSL	SL	MOD	SV	SV
5m	5m	6m	VSL	VSL	SL	MOD	MOD
5m	5m	12m	VSL	VSL	VSL	SL	MOD
5m	7m	0m	VSL	SL	SL	MOD	SV
5m	7m	6m	VSL	VSL	SL	MOD	MOD
5m	7m	12m	VSL	VSL	VSL	SL	MOD
7m	3m	0m	VSL	SL	MOD	MOD	SV
7m	3m	6m	VSL	SL	MOD	MOD	MOD
7m	3m	12m	VSL	VSL	SL	SL	MOD
7m	5m	0m	VSL	SL	MOD	MOD	SV
7m	5m	6m	VSL	VSL	SL	MOD	MOD
7m	5m	12m	VSL	VSL	VSL	SL	MOD
7m	7m	0m	VSL	VSL	SL	MOD	MOD
7m	7m	6m	VSL	VSL	VSL	SL	MOD
7m	7m	12m	VSL	VSL	VSL	SL	MOD

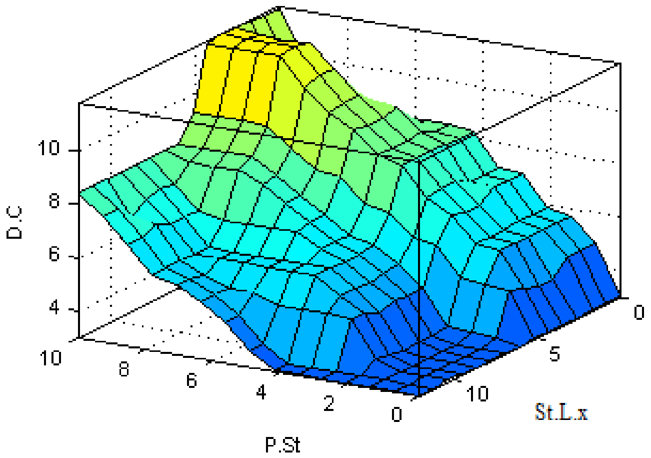


Figure 14 Damage category surface for pipeline settlement and settlement location in case of four inputs.

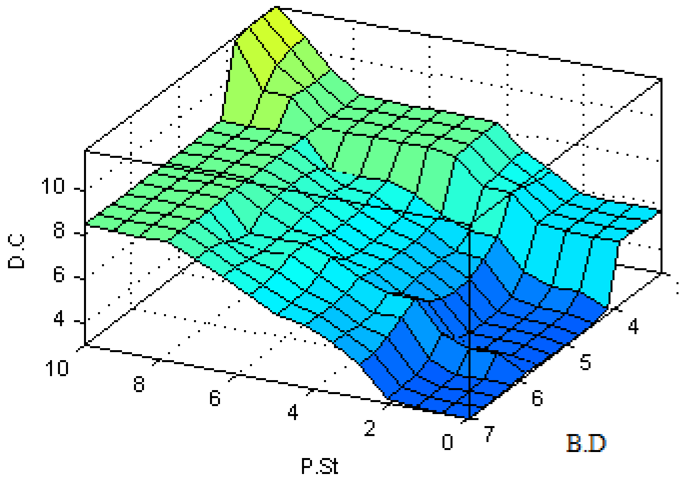


Figure 15 Damage category surface for pipeline settlement and burial depth in case of four inputs.

Table 9 Evaluation of potential damage for four parameters

	Pipeline Settlement	Settlement Location	Building Location	Burial Depth	Damage Category
IF	1.5%D	0.0m	3.0m	3.5m	SL
	3%D	3.5m	4.5m	4.5m	MOD
	4.5%D	11.5m	6.5m	6.5m	VSL
	8%D	0.0m	6.5m	4.5m	MOD
	9.5%D	7.0m	5.0m	3.0m	SV
	AND	AND	AND	THEN	

6. Summary and Conclusions

The purpose of this study is to extend the research done in introducing the fuzzy logic for damage assessment of buildings due to nearby pipeline deterioration. The main contribution in this research is applying up to four different parameters of pipeline deterioration at the same time. This requires the use of Matlab to build synchronized four membership functions as input functions and a huge number of rule bases which play the role of experts in the decision. By using data from the major sewer pipeline projects in Egypt and detecting the main causes of failure. We choose here four parameters (pipeline settlement, settlement location, building location and burial depth). It can be concluded from this research that:

1. Fuzzy decision support tool is a very efficient and powerful tool for evaluating the damage

categories of buildings due to different parameters of sewer pipeline failure. This is time saving and provide a guide for less experienced engineers.

2. Using fuzzy logic for studying the effect of four different parameters of pipeline deterioration at the same time on the damage of nearby buildings helps to evaluate the weight of each parameter with respect to the others.
3. By including the four mentioned parameters of pipeline failure. It was found that the value of pipeline settlement has the major impact on the damage of adjacent buildings, more than the settlement location, the building location and the burial depth.
4. Also, we can add that, following the pipeline settlement, the settlement location has more effect on building damage followed by the burial depth, then the building location.

Potential studies:

a. The use the Genetic Algorithm (GA) to optimize the parameter of FDST will be very useful in minimizing the error according to defined fitness function. Also, the use of the neural network for design system like FDST in civil engineering will be good extension to this research.
b. Build new fuzzy decision support tool by using new data in the practical range for pipes, soil properties and dimensions to provide a database library to predict potential damage in surrounding buildings in existing and future sewer pipeline projects.
c. Fuzzy expert system is flexible to enter other parameters with different ranges for other applications in civil engineering.

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