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A Comprehensive Environment Modeling for Groundwater Flow for Assessing the Impact of Tunneling Works on Metro Rail Corridor in the Area of Chennai (India)

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Abstract

This paper presents the impact assessment of the tunneling works on aquifer's hydrogeology in the area of Chennai metro rail corridor using groundwater numerical model (MODFLOW3D). The comprehensive environment model is used to estimate the groundwater flow system and the groundwater levels in the study area, during the tunneling period. The comprehensive environment modeling period was selected from 1995 to 2016. According to the available data and the project phasing. Three scenarios are chosen according to the time schedule of the progress of the tunneling work. The comprehensive environment model was calibrated, validated and predicted for the change in the rate and direction of movement of ground water before and after the construction of underground tunnel sections. The comprehensive environment model shows increase and decrease of water levels in the observation wells of the study area due to the obstruction created in the ground water flow regime.

Keywords: modeling, metro rail, environment, Chennai

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INTRODUCTION

Underground development is an important tool in developing and reshaping urban areas to meet the challenges of the future. Placement of infrastructure and other facilities underground presents an opportunity for realizing new functions in urban areas without destroying heritages or negatively impacting the surface environment (Wout 2016). Urbanization occupies a puzzling position in country development and growth, global economic development, energy consumption, natural resource use, and human wellbeing (Jain et al. 2016, McDonald et al. 2011, 2014, Mondal et al. 2015, Pandey and Joshi 2015, Uddameri et al. 2014). Infrastructure developments such as tunneled metro rail corridor often interfere directly with water resources. The changes due to the subsurface structure causes numerous anthropogenic impacts make urban geological and hydro geological issues complex. Huggenberger and Epting (2011) comprehensive environment models for Groundwater describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. (Kumar 2014). During tunneling the trenches are excavated and to keep it dry groundwater should be pumped out from its bottom part. This causes lowering of groundwater table in surroundings of the trench. (Spalvins et al. 2012). Due to tunneling the potential to cause groundwater drawdown and the ground settlement that may affect existing structures will be an issue (France and Cammack 2010). The assessment of water quantity was done by developing a numerical 3D model (Visual Mod Flow) to assess the impact of tunneling work in the underground sections of metro rail corridor, Chennai. Flow direction changes and the ground water level were assessed during the progress of tunneling work.

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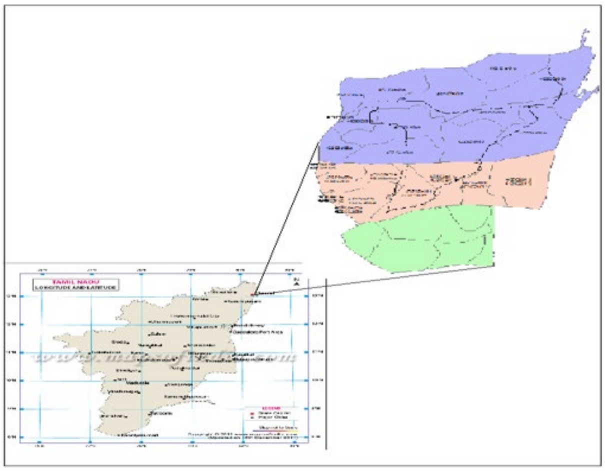

Fig. 1. Base Map of the Study Area

Fig. 2. Metro Line with Station Points

STUDY AREA

Underground metro rail corridors of Chennai city was selected as study area. Chennai is the fourth-largest city in India. The climate is hot and humid but the breeze blowing from the sea makes the climate bearable. It is located with the latitude of 13.0827° N, and longitude of 80.2707° E. It covers a geographical area of about 174 Sq.km with the population of around 8.5 million and an average annual rainfall of 1200 mm. The study areas geology comprises of Clay, Shale and Sandstone. The study area is dividing into three zones. The places covered with river bank and coasts are taken as sandy areas. The lower part of metro rail corridor are taken as hard rock areas and the upper part is almost covered with clay and it is shown in **Fig. 1**.

CHENNAI METRO RAIL

The Chennai Metro Rail is a rapid transit system in Chennai, Tamil Nadu, and India. For the rapidly growing population and traffic volumes in Chennai city becomes the need for a new rail based rapid transport system .The system provides a fast, reliable, convenient, efficient, modern and economical mode of public transport. The underground corridor covers from Washermanpet to Saidapet with a length of 14.3 kms and the corridor with a length of 9.7 kms. From Chennai Central to Anna Nagar 2nd Avenue will be considered for analysis and it is shown in **Fig. 2**.

DATA COLLECTION

For the comprehensive environment model development data collection is very crucial. The datas are collected from Institute of water studies (IWS), Centre Ground Water Board (CGWB) and TWAD. The data include hydrological, lithological, rainfall and well data. A field reconnaissance survey was carried out to have a complete understanding of site hydrogeology on Chennai, India.

Water Level Data

Nine observation wells were identified from the government maintained monitoring wells in and around the metro rail corridor for the water level .Water level data was collected for a period of 15 years to study the water fluctuation pattern of the wells before starting of the tunnel construction. In addition, 20 observation wells were located opposites to the underground sections of the corridors. Water level was measured in the observation wells for every two weeks and it was recorded for the period of two and half years from June 2014 to December 2016 to assess water level pattern after the construction of metro rail corridor.

Lithological Data

Bore well datas were collected for the two underground corridor sections from the households dwelling in the nearby areas of the corridor section. It was mapped using ROCKWORKS Software. The lithological plot of the Chennai Central to Anna Nagar 2nd Avenue covering for a length of 9.7 kms is shown in the **Fig. 3** and the same for the corridor length 14.3 kms covering from Washermanpet to Saidapet as shown in **Fig. 4**.

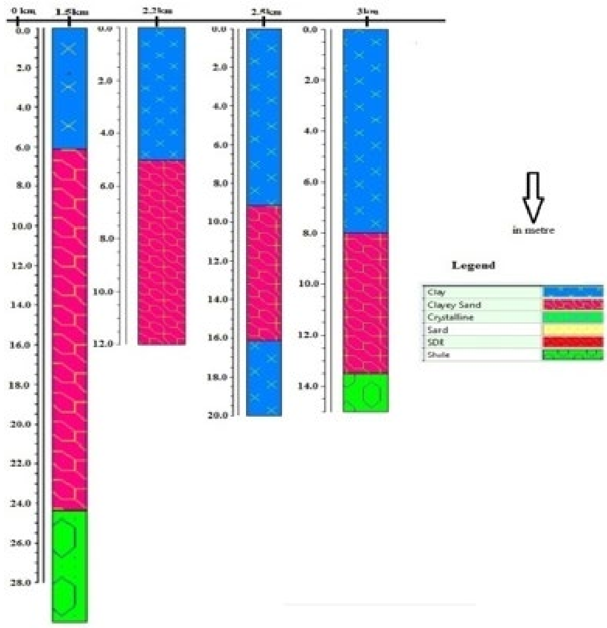

Fig. 3. Lithology Plot of Chennai Central to Anna Nagar

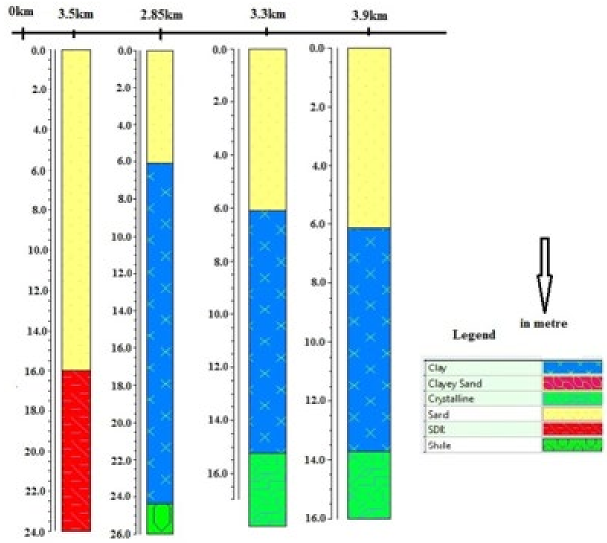

Fig. 4. Lithology Plot of Washermenpet to Saidapet

MODFLOW INPUT

Base Map

The line map of the Chennai metro rail corridor was given as a base map for the model input. Geo-referencing has been done for two points one for the airport as (x=1442346.432, y=8898966.237) and another for Washermenpet as (x=1457656.329, y=8910899.292) as model co-ordinates as shown in **Fig. 5**. The comprehensive environment model simulates the ground water flow for the study area with 60 rows and 80 columns, with two vertical layers.

Fig. 5. Base Map of Modeling

Governing Equations and Groundwater Comprehensive Environment Model Selection

Three-dimensional groundwater flow can be mathematically represented given the following equation Eq. (1) based on water mass balance and Darcy's law equations (Bear 1972):

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-Q = S_s\frac{\partial h}{\partial t}$$

K_{xx}, K_{yy}, K_{zz} = hydraulic conductivity along the x, y, z axes which are assumed to be parallel to the major axes of hydraulic conductivity;

h = Piezometric head;

Q = Volumetric flux per unit volume representing source/sink terms;

S_s = Specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material.

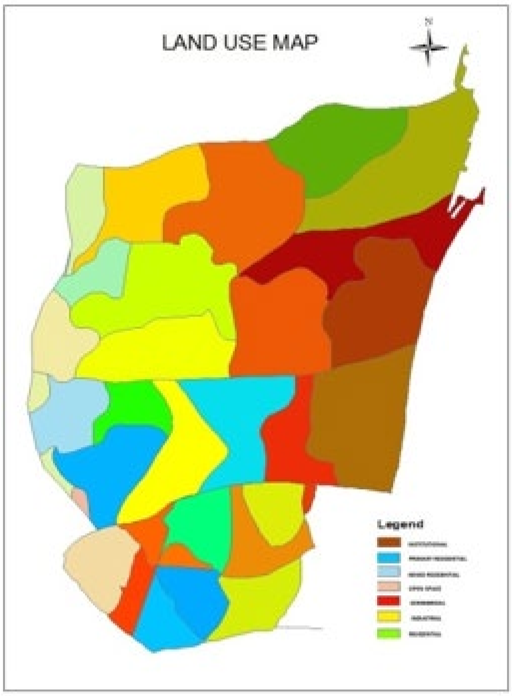

Fig. 6. Land Use Map

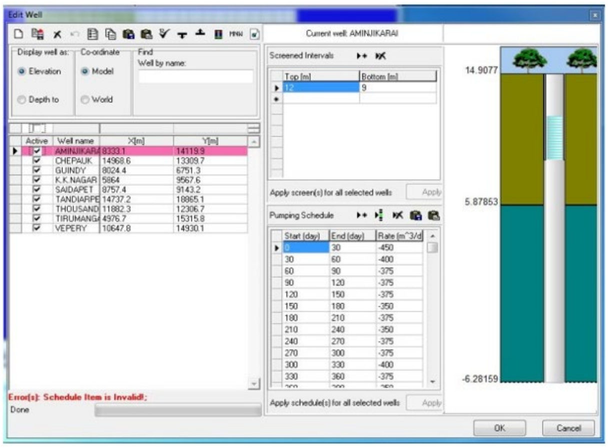

Fig. 7. Pumping rates of Study Wells

PROCEDURE FOR GROUND WATER COMPREHENSIVE ENVIRONMENT FLOW MODEL

Model Conceptualization

A systematic way of describing the field conditions for the ground water flow is explained in Model Conceptualization. The conceptual model was developed based on the studies done on the water level fluctuation, borehole lithology and geology of the study area. Since the ground water was found to occur in weathered rocks, the aquifer was assumed to be consists of the top soil and the lower weathered and fractured rocks as one layer below the bottom as another layer, unconfined aquifer.

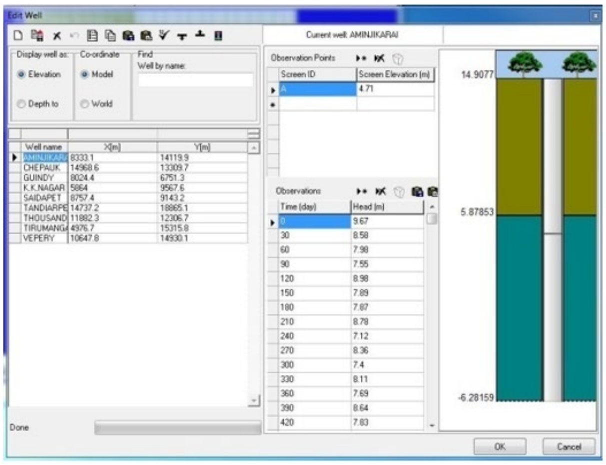

Fig. 8. Head Observation Wells

Pumping Wells

Based on the land use of the study area shown in **Fig. 6** and the pumping data from the water board, well inventory and their pumping rate and their usage are calculated. The pumping wells are located in the grid and the pumping rate is entered. Positive rates are used for injection. Negative rates are used for pumping. In the study area there is no injection wells. Pumping data entered in modeling is shown in **Fig. 7**.

Head Observation Wells

Excel spread sheets are created for the head observation wells for the nine secondary wells and the twenty primary wells with latitude and longitude details and observed head of the wells with the respective times. The observed head data for the secondary wells from 1995 – 2016 and the secondary wells from June 2014 to December 2016 was generated and it was given to the model head observation input. Head Observation data entered is shown in **Fig. 8**.

Sensitivity Analysis

Within a reasonable range the model input parameters are varied and the relative change is observed in the model response. The process of doing this procedure is called sensitivity analysis. The changes in the hydraulic head and flow rate are noted. A sensitive will give good response for the future predictions.

Model Design

Model is designed includes the parameters that are given in the table below. The input parameters given under are used to develop the calibrated model.

Table 1. Aquifer Properties

S. No	Model Properties	Values
1	Hydraulic Conductivity in longitudinal direction, K_x	5.00E-05
2	Hydraulic Conductivity in lateral direction, K_y	5.00E-05
3	Hydraulic Conductivity in Vertical direction, K_z	5.00E-07
4	Specific yield, S_y	2.00E-01
5	Effective porosity	1.50E-01
6	Total porosity	3.00E-01
7	Specific storage	1.00E-05

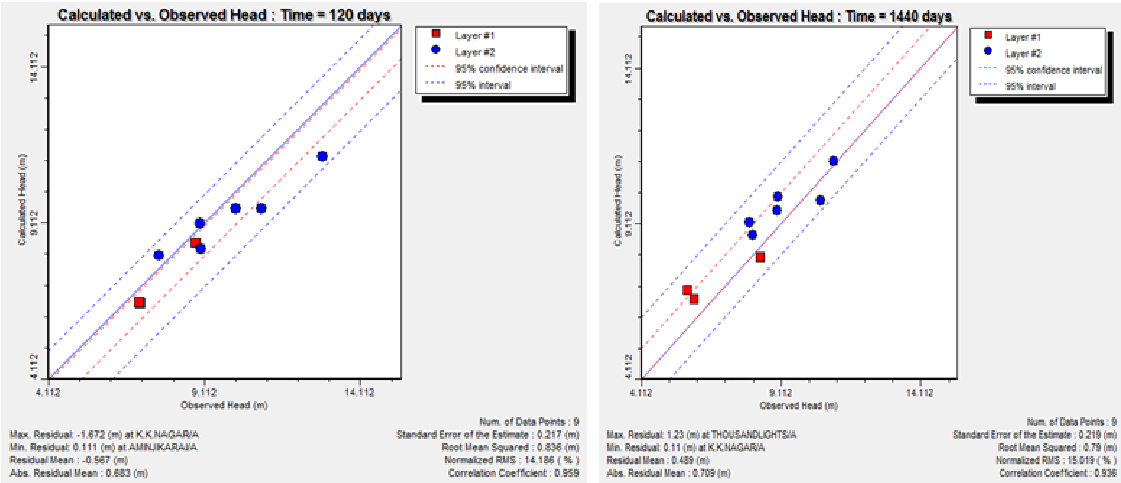

Fig. 9. Model Calibration for 120 days and 1440 days

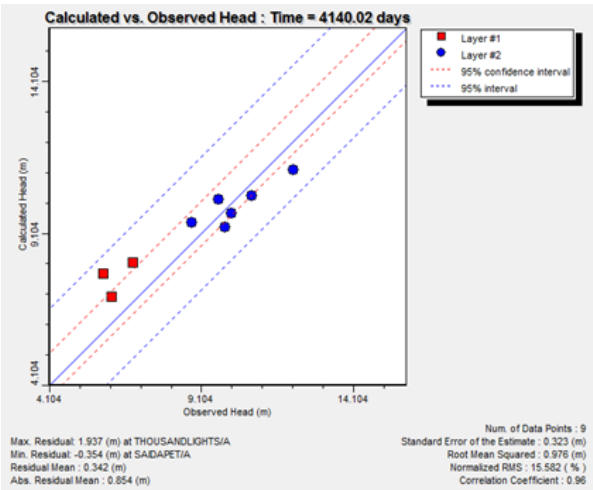

Fig. 10. Model Validation for 4140 days

Model Calibration

The study areas field condition characterization is very essential for the good calibration. The comprehensive environment model input parameters values are changed to match the field conditions to an acceptable limit. Model calibration is done for the period from 1995 – 2005. The observed and calculated head of the observation wells are well correlated at 99% of confidence level. The plot of observed versus calculated head for the time step 120 days and 1440 days is shown in the **Fig. 9**.

Model Validation

Model Validation is the process of further calibration of the model. Model validation is done for the period from 2006-2011. The comprehensive environment model has reproduced the same values as in model calibration. Hence it is evident that the model validation responded well for the measured changes in the field conditions. Again the observed and calculated head was well correlated and it was presented for the time step of 4140 days in the **Fig. 10**.

Model Prediction

Model prediction will predict the future ground water flow and evaluates the alternatives. The outcomes of the comprehensive environment model prediction should correlate with the assumptions in the model and also the uncertainty of the model input parameters. In this model, the prediction is done purely based on the progress of the tunneling work. The progress chart of tunneling work is shown in **Fig. 11** (Owen et al. 1996).

Under four scenarios of progress of tunneling that is from January 2012 to December 2013, January 2014 to December 2015, January 2016 to March 2017 and the future prediction from 2017-2020 was predicted for ground water flow analysis. In the base map the progress of tunneling for the respective periods was done by constructing the wall provision in the corridors.

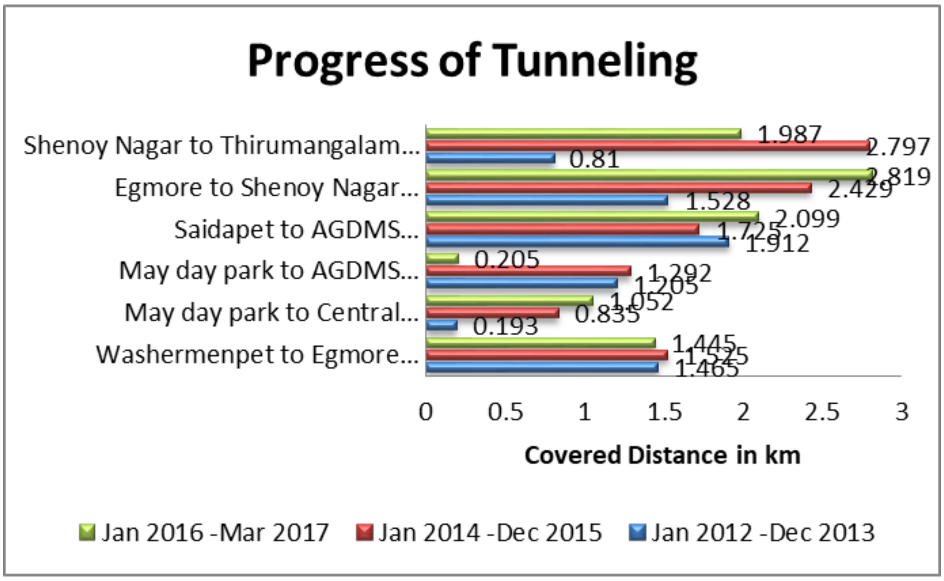

Fig. 11. Progress Chart of Tunneling Work

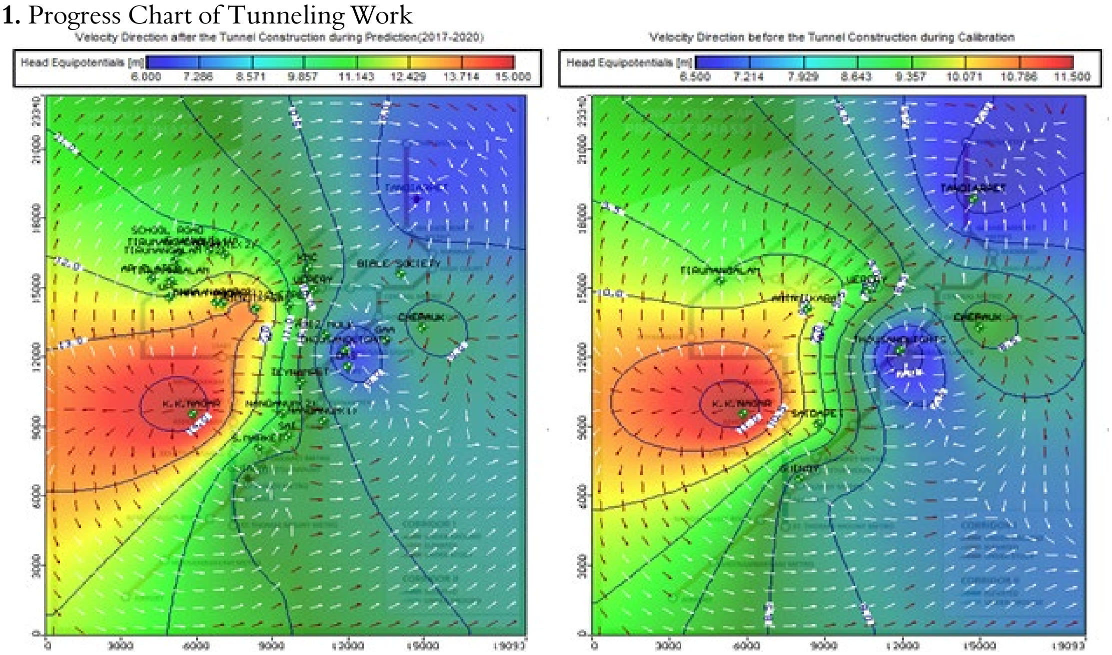

Fig. 12. Velocity Direction Changes from the Calibration to Prediction

Under the three scenarios of the progress of tunneling the velocity direction seems to follow the similar, but after the complete construction of the tunneling the flow direction changes as shown in the **Fig. 12**. Before the construction the contour gradients which are closely spaced got distorted after the construction of the tunnel. The Head equipotential before the tunneling varies from 6.5 m to 11.5 m, but after the construction the head equipotential varies from 6.00 to 15.00. Hence it is clearly evident that the tunnel construction behaves as a barrier and the changes in the direction of the flow makes the head equipotential higher at one end and lower at the opposite side of the tunnel.

CONCLUSIONS

Comprehensive environment Groundwater model has proven to be an efficient means to simulate regional groundwater system in a large scale. It is well proven that ground water models are actually simplifying the complexity of real time and extends an effective support towards decision making process. The assumed hydraulic parameters, boundary conditions and the availability of data make the outcome of model good. In this model, the simulated hydraulic heads are well correlated with the observed hydraulic heads during the model calibration. After the sensitivity analysis the comprehensive environment model results shows good-fitness of the measure data, which indicate the comprehensive environment model is reliable. The variations in the direction of flow was observed only after the complete construction of tunneling work in spite of three different progress of time. Different hypothesis conditions can be performed using this model to predict the groundwater levels variation in the metro rail corridor. Hence this comprehensive environment model will be referred for an effective management of ground water problem in the study area.

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