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浅谈徐州古河道冲积层对岩溶塌陷及工程建设的影响

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摘要:历史上水系的变迁导致徐州古河道十分复杂。文章对徐州古河道的变迁、潜蚀特征、识别特征、深度特征、结构特征进行了分析,并分析了古河道对岩溶塌陷及工程建设的影响。结果表明:(1)自晚更新世以来,共有5条河流流经徐州,其中晚更新世古河道有2条,全新世古河道有3条;(2)徐州古河道冲积层具有“新”、“软”、“杂”、“变”等特点;(3)古河道为岩溶塌陷创造了有利的地质结构,其一形成了相互叠加的粉土、粉砂堆积物;其二对徐州市区内稳定分布的老黏土进行冲刷,形成了下伏岩溶含水层的补给天窗;(4)古河道形成的粉土、粉砂层富水性强,工程施工时易产生涌砂现象,同时古河道冲积层冲埋隐伏的构筑物对基坑工程及浅基础建筑物稳定性会产生较大影响,工程建设时应当采取相应的工程措施。

关键词:古河道;岩溶塌陷;工程特性;影响

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0 引言

徐州位于江苏省北部,地处苏鲁豫皖四省接壤处,东襟淮海,西接中原,南屏江淮,北扼齐鲁,素有“五省通衢”和“兵家必争之地”之盛誉,既是淮海经济区的中心城市,又是江苏省重点规划建设的三大都市圈核心城市之一。随着城市进程加快,岩溶塌陷频发,已严重制约徐州城市的发展^[1],尤其近年来所发生的岩溶塌陷点基本都是分布在覆盖型岩溶区古河道附近^[2-3],那么古河道与岩溶塌陷两者之间是否存在直接或间接的联系?古河道对工程建设存在哪些影响?因此非常有必要带着这些疑问对徐州古河道变迁、分布、特征及冲积层力学特性开展系列

的研究^[4-5]。

1 古河道变迁及特征

1.1 古河道的变迁

徐州地处古淮河的支流沂、沭、泗诸水的下游,受黄河夺汴入泗、运河的改道的影响,原本以泗河为干流注入淮河的沂沭泗水系成独立水系^[6]。历史上黄河泛滥导致徐州河道多次改迁,同时河道河床长期南北摆动并挟带大量泥沙,形成了广泛的黄泛冲洪积平原^[7-11]。据文献记载,从1128年黄河侵淮夺泗至1855年,黄河流经徐州,七百年间黄河多次泛滥^[12],徐州城多次被淹没并被泥沙淤积掩

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埋,形成了独特的“黄泛层+城下城”。在古河道以及两侧泛滥地区,堆积了大量粉土、粉砂。由于该类土沉积时间短,结构松散,工程性质较差,埋藏浅分布广,是徐州地区各类建筑工程比较常见的工程地层^[13]。

依据查阅的地方志资料及历史上水系变迁资料,笔者认为自晚更新世以来,共有 5 条河流流经徐州(图 1),其中晚更新世古河道有 2 条,全新世古河道有 3 条。

晚更新世的 2 条古河道均发源于山东境内,从徐州市区北部入境。一支经马坡镇—郑集镇西,另一支从何桥镇向东出发,最终两支汇合后,流向大彭镇一带。

全新世的 3 条古河道即古泗水、古汴水和黄河故道。其中泗水从徐州市区北部入境,经蔺山村南大致沿着运河向南进入市区;汴水从西部安徽入境,然后泗水、汴水在市区三中—文化宫一带会合,向南经新生街、溶剂厂向东南流出市区;黄河故道由于黄河的多次泛滥、改道,最终由西北向东南呈反“S”穿过徐州地区,尤其在黄河故道附近形成的垄状高地,地势较高,成为了天然分水岭。

1.2 古河道的特征

1.2.1 古河道侵蚀及识别特征

由于不同时期古河道各具不同侵蚀、识别特征,因此古河道形成的堆积物物性差异也较大(如图 2)。根据浅地震物探解译及钻孔剖面资料显示:晚更新世古河道内沉积物为粉土、细砂及中砂,呈夹层状存在于老黏性土中,部分区段与下伏碳酸盐岩直接接触;全新世古河道以侵蚀作用为主,当时未留下沉积物,后来为黄河带来的粉土、粉砂填满掩埋,古河道内沉积的粉土、粉砂以灰色、灰黑色为主,底板标高较低,最低在 12 m 左右。

1.2.2 古河道深度特征

根据物探解译及钻孔资料,可依据古河道内与古河道附近粉砂、粉土层厚度差异可推算古河道的深度。研究结果显示:汇合之前古汴水古河道内粉砂、粉土层厚度略大于泗水古河道的粉砂、粉土层厚,汇合之后古河道侵蚀作用显著增强,粉砂、粉土层厚度也相应增加。以全新世古泗水、古汴水古河道为例:古河道汇合之前,西北部大彭镇附近汴水古河道粉砂、

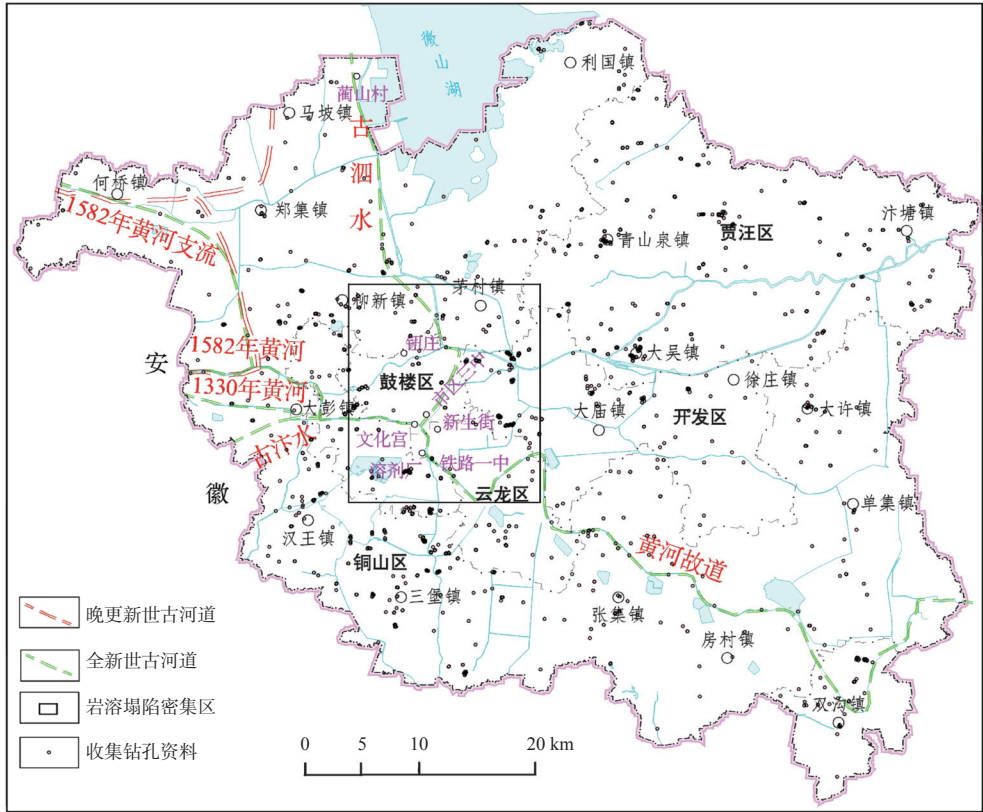


图 1 徐州古河道变迁图

Fig. 1 Xuzhou paleochannel distribution map

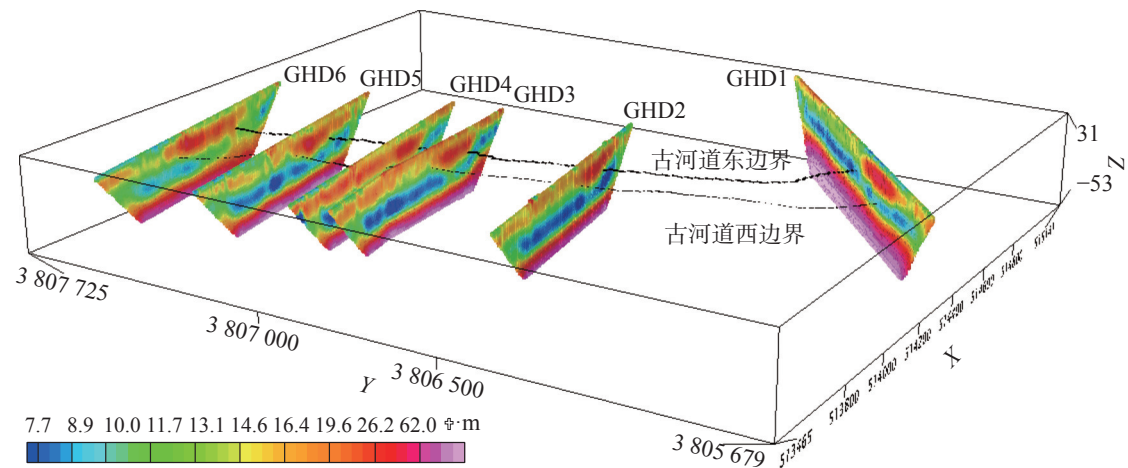


图 2 高密度电阻率反演电阻率断面三维立体图(钮庄附近古河道)
Fig. 2 3d stereogram of high density resistivity inversion of resistivity section (near Niuzhuang)

粉土层厚度约为 17 m, 向东南厚度有逐渐增加的趋势, 汇合之前最大厚度 20 m。东北部泗水古河道附近粉砂、粉土层厚度约为 14 m, 向西南厚度也呈逐渐增加的趋势, 汇合之前最大厚度为 18 m。根据资料解译推算, 汇合之前汴水古河道深 7~10 m, 泗水古河道深 3~5 m。古河道汇合之后, 古河道附近粉砂、粉土层厚度明显增加, 粉砂、粉土层厚度可达 27.2 m,

古河道深 12~15 m(图 3)。

1.2.3 古河道地层结构特征

根据钻孔资料显示, 古河道河床内主要有两种土层结构: 在河流切割基岩地段, 老黏性土被完全侵蚀, 粉砂、粉土直接覆盖在碳酸盐岩之上, 形成了砂性土单层结构; 古河道内其余地段河流未切割至基

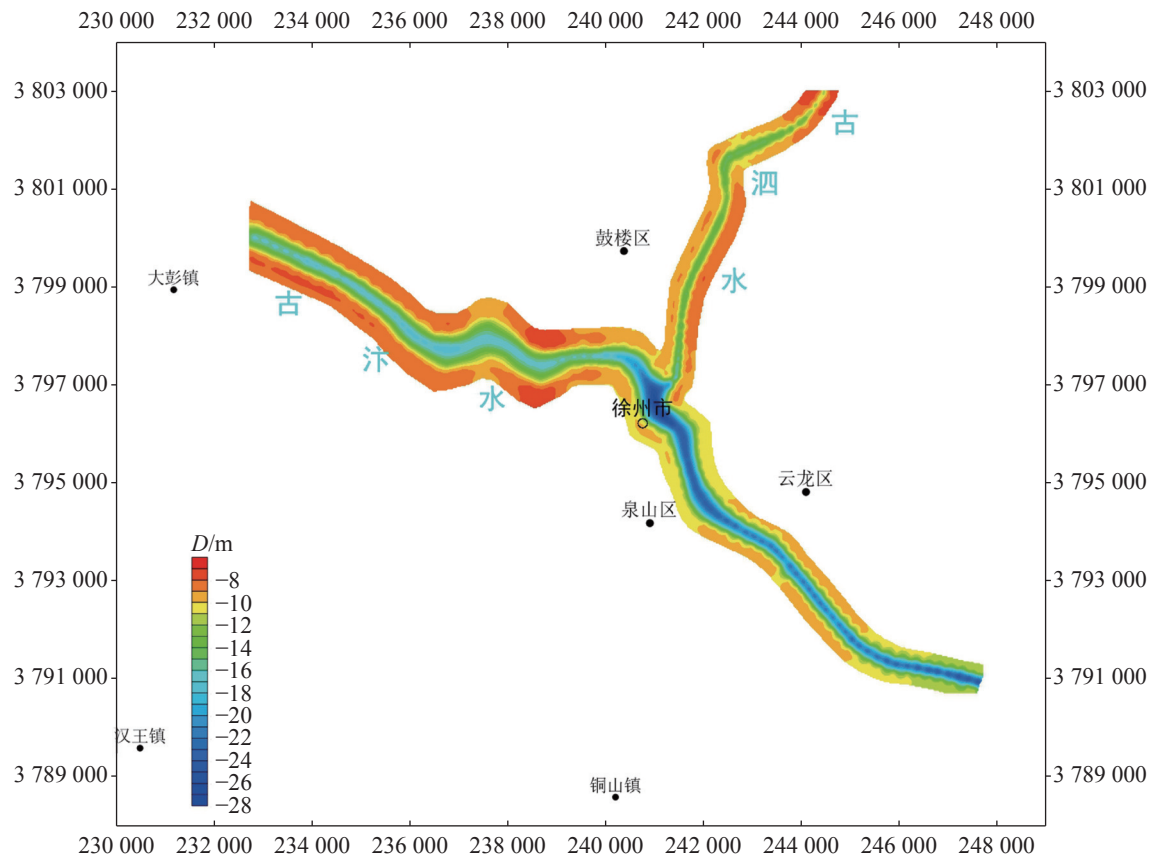


图 3 全新世古河道粉砂、粉土层底板埋深平面示意图
Fig. 3 Diagram of buried depth of mealy sand and silty soil floor of the Holocene paleochannel

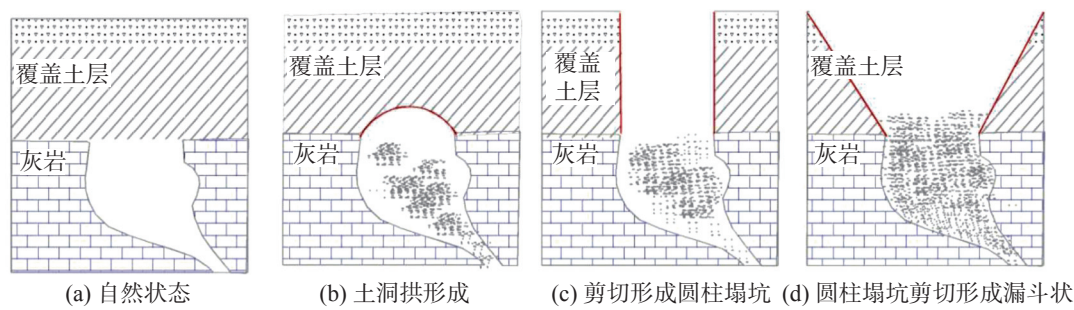


图 6 砂性土—老黏性土双层结构区域岩溶塌陷机制简图

Fig. 6 Schematic diagram of karst collapse mechanism in the area of sandy soil-old clay with double structure

表 1 古河道冲积层主要物理力学指标 (平均值)

Table 1 Main physical and mechanical indexes for the paleochannel alluvium (average values)

地层时代	岩组名称	主要物理力学性质						
		含水率 <i>w</i> /%	孔隙比 <i>e</i>	液性指数 <i>I_L</i>	压缩系数 <i>a</i> ₁₋₂	粘聚力 <i>c</i> /Kpa	压缩模量 <i>E_s</i> /MPa	标贯击数 <i>N</i> /击
全新统Q ₄	砂土组	30.5	0.82	0.81	0.47		4.37	8
	粉土组	27.2	0.81	0.80	0.42	12	3.73	9
	黏性土组(新黏土)	34.2	0.98	0.97	0.61	16.3	0.80	3
更新统上段Q ₃ ³	黏性土组(老黏土)	24.3	0.69	0.31	0.39	49	1.41	15
更新统中段Q ₃ ²	黏性土组(老黏土)	27.2	0.69	0.31	0.18	59	1.77	
更新统下段Q ₃ ¹	黏性土组(老黏土)	23.9	0.80	0.27	0.14	57	21.2	

注：含水率表征土体中所含水分重量的百分比；孔隙比表征土体中孔隙体积与固体颗粒体积之比；液性指数表征土的软硬状态，表示天然含水率与界线含水率相对关系的指标；压缩系数表征土体压缩性大小的物理量；压缩模量表征物探在受三轴压缩时应力与应变的比值；粘聚力表征物质内部相邻各部分之间的相互吸引力；标贯击数表征土体的密实程度及承载能力的指标。

Note: Water ratio represents the weight percentage of water contained in a soil mass; porosity ratio represents the ratio of pore volume to solid particle volume in soil mass; liquidity index represents the hard and soft state of soil, which indicating the relative relationship between natural and boundary water content; coefficient of compressibility is a physical quantity that represents the compressibility size of soil; modulus of compressibility represents the ratio of stress to strain when geophysical exploration is under triaxial compression; cohesion represents the mutual attraction between adjacent parts of a substance; standard penetration number indicates the compactness and bearing capacity of soil mass.

黏土进行冲刷，形成了下伏岩溶含水层的补给天窗，为岩溶塌陷的形成创造了有利的地质结构条件，这正是塌陷点密集分布在古河道附近的最主要原因。

3 古河道冲积层力学特性及对工程建设的影响

3.1 古河道冲积层力学特性

根据物理力学性质的差异将古河道附近粉砂类分为砂土组和粉土组，黏土类划分为新黏土组(全新统)和老黏土组(更新统)两个亚类，其主要物理力学指标见表 1。

从表中可看出，砂土组松散—稍密、含水量高、孔隙比较高、压缩性中等等特点；粉土组稍密、含水量中等、孔隙比较高、压缩性中等等特点；新黏土组

含水量高、孔隙比高、软塑—可塑、压缩性高、粘聚力低等特点；老黏土组含水量低、孔隙比较低、可塑—硬塑、压缩性中等、粘聚力低—中等等特点。这些力学特性反映出覆盖层一方面易诱发砂质粉土饱水振动液化流失而产生塌陷；另一方面黏性土粘聚力较小，当上部土层的自身重力超过土层所能承受荷载时，在水位反复波动情况下易形成土洞而发生岩溶塌陷。

3.2 古河道冲积层对工程建设的影响

3.2.1 粉土、粉砂层对工程建设的影响

由于徐州北东和南西两端多为丘陵，这种地形特点决定了过境古河流只能在山体之间较小的范围内摆动，使不同时期的粉土、粉砂堆积叠加。研究显

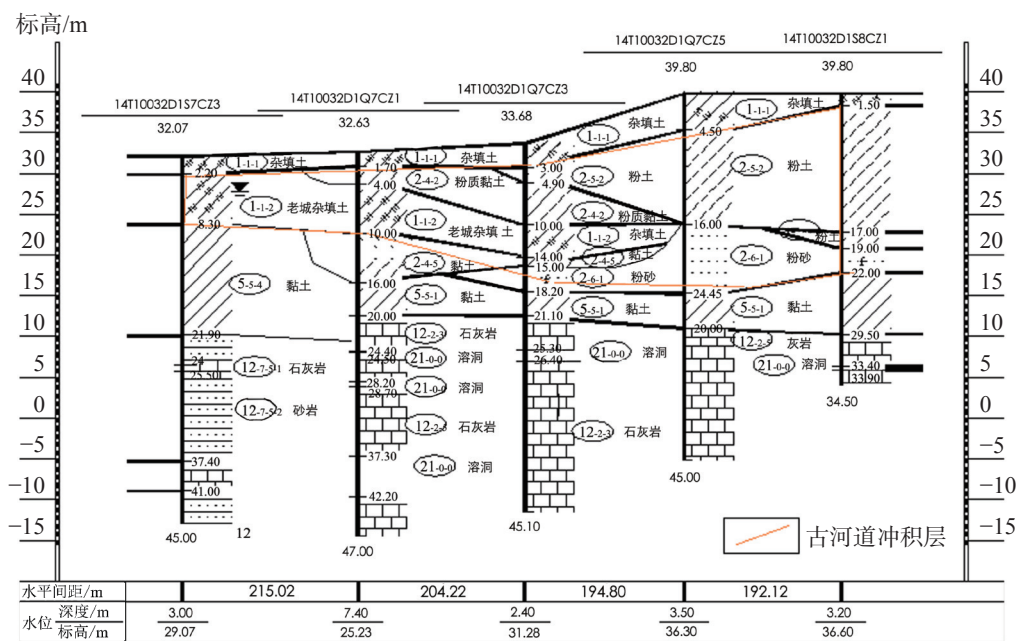


图7 古河道冲积区(文化宫站附近)工程地质剖面图

Fig. 7 Engineering geological section of paleochannel alluvial area (near Cultural Center Station)

示这套松散的粉土、粉砂层地震液化等级为中等—严重液化、富水性好、土洞发育强度高、易发生岩溶塌陷,同时地基稳定性亦差。例如,徐州地铁沿线文化宫站附近、物资市场站附近、淮塔东路至和平路站区间附近均有古河道经过,这对地铁盾构施工及基坑降水将会产生显著的影响。尤其文化宫站古河道附近松散岩类孔隙水富水性比较强,标准单井涌水量达 $1\,000\sim 2\,000\text{ m}^3\cdot\text{d}^{-1}$ 。当盾构穿越古黄河河道时,如施工不当而产生的水头差,会致使粉土、粉砂产生涌砂现象,将导致地面沉降。同时开挖揭露具有承压的粉土、粉砂含水层时,易诱发承压水涌水,导致隧道变形、坍塌(图7)。

3.2.2 冲埋隐伏构筑物对工程建设的影响

根据古河道变迁特征,徐州先有汴水、泗水泛滥,后有黄河泛滥。而不同时期泛滥形成的冲积层冲埋了大量的构筑物,因此可总结为徐州新形成的地层具有“新(多为黄泛物,年代新)”、“软(含水量大,地层多具高压缩性)”、“杂(地层中含地下古城中的砖、瓦、石块及陶片等现象)”、“变(黄泛物大量覆盖,不仅埋没了古城文化,同时使地形地貌发生变化)”等特点。经钻探资料揭露显示,形成的淤积文化层堆积厚达10余米,其中地下4~6 m 遗存相对比较完整,主要集中在徐州的市中心。这些冲埋的隐伏构筑物对地基的稳定性、均匀性有很大的影响。如在古彭

城广场附近进行工程勘察时,在埋深7~12 m 见块石,块石间用米浆胶结,呈东西条带状分布,带宽10 m 左右,北薄南厚,埋深北深南浅,厚度16~47 m,应为故黄河护堤。而“城下城”现象对地基选择及处理带来较大的影响,如在解放北路某大厦配楼施工勘察过程中,钻探揭示场地东南角地下4.4~6.7 m 为碎石堆砌的墙体,走向SE-NW,宽约3 m,为消除其影响,这些区域建筑采用大直径灌注桩基础,桩基穿过墙体直达基岩,直接致使工程造价翻倍。

4 结 论

(1)自晚更新世以来,共有5条河流流经徐州。晚更新世古河道有2条,均发源于山东境内,从徐州市区北部入境。全新世有3条古河道,即古泗水、古汴水和黄河故道;

(2)徐州古河道地层是先有汴水、泗水泛滥,后有黄河冲积形成的,地层具有“新”、“软”、“杂”、“变”等特点;

(3)古河道所带来冲积层物理力学特性差异较大。砂土组松散—稍密、含水量高、孔隙比较高、压缩性中等;粉土组稍密、含水量中等、孔隙比较高、压缩性中等;新黏土含水量高、孔隙比高、软塑—可塑、压缩性高、粘聚力低;老黏土含水量低、孔隙比较低、可塑—硬塑、压缩性中等、粘聚力低—中等;

(4)古河道为岩溶塌陷的发生创造了有利的地质结构条件,一方面形成了相互叠加的粉土、粉砂堆积物,另一方面对徐州市区内稳定分布的老黏土进行冲刷,形成了下伏岩溶含水层的补给天窗,这是塌陷点密集分布在古河道内的最主要原因;

(5)由于古河道附近富水性较强,地铁盾构施工时易导致粉土、粉砂产生涌砂现象。同时古河道特殊的地层结构及工程地质特性,对基坑工程及浅基础建筑物稳定性将产生较大影响,工程建设时应当采取相应的工程措施。

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Influence of the Xuzhou paleochannel alluvium on karst collapse and engineering construction

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Abstract According to historical records, from 1128, when the Yellow River encroached the Huai river to flood the Sishui river, to 1855, when the Yellow River flowed through Xuzhou, the Yellow River flooded many times, causing

several changes in the direction of the surface water system and the repeated scouring and burying of the paleochannel, which has contributed to the complexity of today's paleochannel in terms of its direction, burial depth and stratigraphic structure, over these seven hundred years.

In this paper, the characteristics of changes, erosion, identification, depth and stratigraphic structure of the Xuzhou paleochannel are analyzed through data collection, field exploration, drilling, geophysical exploration and other geological methods, and the influence of alluvium formed by the paleochannel on karst collapse and engineering construction has been studied. It is concluded that since the late Pleistocene, a total of 5 rivers have flowed through Xuzhou. Among them, there are 2 paleochannels in late Pleistocene, both originating in Shandong and entering Xuzhou City from north, and 3 in the Holocene, namely, the ancient Sishui river, the ancient Bianshui river and the ancient Yellow River. Besides, the strata of the Xuzhou paleochannel were firstly formed by the flood of the Bianshui river and the Sishui river, and then by the alluviation of the Yellow River. Therefore, the strata are characterized by "new" (The age is young, mainly formed by the flooding of the Yellow River.), "soft" (Many strata present the large compressibility with high water content), "miscellaneous" (The strata contain bricks, tiles, stones and pottery of the underground ancient city.), "changing" (The large area of cover caused by the flooding of the Yellow River not only buried the ancient city, but also changed the landform). Furthermore, the paleochannel has created favorable geological structure for the formation of karst collapse because the formation of superimposed silt and silt deposits as well as the scouring to the old clay that is steadily distributed formed a replenishment skylight of underlying karst aquifer. This is also the main reason why the collapse points are densely distributed near the paleochannel. Finally, due to the strong water abundance near the paleochannel, the construction of the subway shield is subject to the sand inrush caused by silt and mealy sand. At the same time, the special stratigraphic structure and engineering geological characteristics of the paleochannel will have a great influence on the stability of foundation pit engineering and shallow foundation buildings, and hence corresponding engineering measures should be taken during the project construction.

Key words paleochannel, karst collapse, engineering properties, influence

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pipelines, which provides conditions for the occurrence of water inrush disasters and thus increases disaster possibility.

The assessment result is in consistency with the actual situation of water inrush and tunneling. The consistency indicates that the risk assessment index and its system are applicable to water inrush assessments in karst tunnel areas. The cloud model intuitively reflects a fuzzy membership of risk; the variable weight theory constructs an equilibrium function, and each index is weighted according to the specific situation. It is a good solution to the problem of mutual neutralization between the indexes in the risk assessment of water inrush in karst tunnels, which is conducive to observing the change range and relative importance of each index. The risk assessment method of water inrush disasters of karst tunnels constructed in this paper can realize the objectivity of risk classification of water inrush disasters in tunnels from a multiple decision-making perspective, which is applicable to the risk assessment of karst tunnels and provides reference for the tunnel quality control and life assessment in the future.

Key words normal cloud model, variable weight theory, karst tunnel, comprehensive membership degree, water inrush disaster

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